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SEP 77 M Y SHAHIN, M I DARTER, S D KOHN

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Development of a Pavement Maintenance Management System
Volume III. Maintenance and Repair Guidelines for Airfield Pavements

CONSTRUCTION ENGINEERING RESEARCH LABORATORY
CHAMPAIGN, ILLINOIS

SEPTEMBER 1977

CEEDO

FINAL REPORT FOR PERIOD OCTOBER 1976-SEPTEMBER 1977

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CIVIL AND ENVIRONMENTAL
ENGINEERING DEVELOPMENT OFFICE
(AIR FORCE SYSTEMS COMMAND)
TYNDALL AIR FORCE BASE
FLORIDA 32403

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This report describes the development of guidelines for determination of maintenance and repair (M&R) needs of airfield pavements. The guidelines are based on the pavement condition index (PCI) and other condition indicators, including rate of deterioration, cause of deterioration, load carry capacity, skid resistance/hydroplaning, surface roughness, and extent of previous M&R. The M&R methods were divided into three general categories: routine, major, and overall. The mean pavement PCI was found to relate strongly to M&R needs

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represented by these three M&R categories. M&R zones for use in selecting the appropriate M&R category were established based on the mean pavement PCI. Other condition indicators are used to further aid in the selection of feasible M&R alternatives. Recommended M&R methods for the different distress types and severity levels were developed. Economic analysis procedures were developed for comparing M&R alternatives.

The airfield pavement condition survey and rating procedures have been successfully field-tested. Performing the condition survey according to these procedures does not require expensive equipment; only a measuring wheel and straightedge are required. The results can be used to rate pavement condition and to select M&R requirements for all pavement features of the airfield. The procedures are useful in assisting the airfield pavement engineer in managing the airfield pavements and obtaining the maximum benefits for available M&R funds to keep the airfield pavements functioning in an acceptable condition. The procedures provide excellent results that can be used to communicate pavement condition and justify M&R needs to management. Based on the successful field trial testing and implementation, it is recommended that the pavement condition survey, rating, and M&R guidelines be implemented.

PREFACE

This report documents work performed during the period 1 October 1976 through 30 September 1977 by the US Army Construction Engineering Research Laboratory under Project Order No 77-014 from the Air Force Civil Engineering Center (AFCEC). On 8 April 1977, AFCEC was reorganized into two organizations. AFCEC became part of the Air Force Engineering and Services Agency. The R&D function remains under Air Force Systems Command as Det 1 (Civil and Environmental Engineering Development Office-CEEDO) HQ ADTC. Both units remain at Tyndall AFB FL 32403. This technical report was completed under the auspices of CEEDO. Mr Donald N. Brown was program manager for AFCEC and CEEDO.

Appreciation is expressed to the following personnel who assisted in development of Maintenance and Repair Guidelines as presented in this report: Roy A. Almandarez, HQ ATC/DEMM; Carl Borgwald, HQ AFLC/DEMM; Don Brown, Det 1 HQ ADTC/CNO; Dale Hokanson, AFIT/DET(AU); Larry Olson, NGB/FSC/DE; William F. Peacock, HQ TAC/DEMM and Charles W. York, HQ MAC/DEMU.

This report has been reviewed by the Information Officer (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

DONALD N. BROWN
Project Officer

GUY P. YORK, Lt Col, USAF
Director of Civil Engrg Dev

L. M. WOMACK
Chief, A/C Operational Surfaces Div

JOSEPH S. PIZZUTO, Col USAF, BSC
Commander

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SECTION I

INTRODUCTION

BACKGROUND

The Air Force presently has a very large inventory (approximately 300 million square yards) of airfield pavements, many of which are fast approaching the end of their economic service life. As a result, maintenance requirements for keeping these pavements in service are steadily increasing, and it is anticipated that this increase will become progressively greater with time.[1] Methods for rational determination of maintenance requirements and adequate assignment of priorities are therefore needed to assure optimum use of limited funds. The Air Force Civil Engineering Center (AFCEC), which identified the need for an airfield pavement maintenance management system, in FY75 contracted with the U.S. Army Construction Engineering Research Laboratory (CERL) for development of such a system.

The complete pavement maintenance management system is expected to include:

1. Improved and field-validated condition survey procedures for jointed concrete and asphalt- or tar-surfaced airfield pavements.

2. Objective methods for determining pavement condition indices (PCIs) based on data obtained from pavement condition surveys.

3. A revised version of Air Force Regulation (AFR) 93-5, Chapter 3, entitled "Airfield Pavement Condition Survey Report."

4. Methods for evaluating the consequences of using various maintenance strategies; the methods will provide procedures for selecting the best specific maintenance strategies based on pavement condition.

5. Methods for assigning maintenance priorities which will assure efficient and economic use of available maintenance funds.

6. A computer package consisting of a data bank and computation system based on all the developments resulting from work described in 1 through 5. The computer package will provide an up-to-date pavement maintenance management system and will be easily adapted to any existing computer used by the Air Force.

[1] Statement of Work, Project Order No. 77-014 (U.S. Air Force Civil Engineering Center [AFCEC], 26 October 1976).

7. Field demonstration of the final version of the pavement maintenance management system at one Air Force base.

An improved condition survey procedure, a method for determining the PCI, and a draft of Chapter 3 of AFR 93-5 (Items 1 through 3) were developed in the initial phases of the study. The results are documented in the first two volumes of this report.[2] The work presented in those volumes primarily consisted of developing airfield pavement condition survey and rating methods for jointed concrete and asphalt- or tar-surfaced pavements. These methods have been field-tested, revised, and validated at several airfields located in different climates and subjected to varying traffic.

OBJECTIVES

The objectives of the current (FY77) work effort are:

1. To assist in the technology transfer of the new pavement condition survey and rating procedures through meetings and field visits with Air Force major command pavement engineers and to assist AFCEC in preparation of a final revision of Chapter 3, AFR 93-5.

2. To develop a computer program to automatically calculate the PCI of a pavement from distress data gathered during a pavement condition survey.

3. To develop guidelines for selecting maintenance and repair (M&R) alternatives based on the PCI and other significant factors such as distress types, quantities, and severities, pavement structure, and traffic.

4. To develop an economic analysis procedure to assist command pavement engineers in comparing all feasible M&R alternatives for each pavement feature.

5. To perform a feasibility study to select an approach for determining the consequences of various M&R alternatives.

APPROACH

The above objectives were achieved through a series of steps:

1. A computer program for performing calculations required to determine the PCI was developed.

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[2] M. Y. Shahin, M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume I, Airfield Pavement Condition Rating, and Volume II, Airfield Pavement Distress Identification Manual, CEEDO-TR-77-44 (AFCEC-TR-76-27).

2. Five major command airfields were visited (1) to accomplish a trial implementation of the survey procedure to determine how technology transfer could be facilitated, (2) to obtain condition survey data on many pavement features, and (3) to obtain condition survey data on some pavement features which have had current laser profiles taken of them.

3. A workshop was held with major command engineers to help analyze field data and obtain further information on current Air Force M&R practices.

4. The data collected during the field visits and workshop were analyzed as a basis for developing (1) guidelines for evaluating the condition of airfield pavement features and selecting M&R alternatives based on results of pavement evaluation, and (2) procedures for performing economic analyses of M&R alternatives.

5. A feasibility study was conducted to select an approach for determining the consequences of various M&R alternatives.

ORGANIZATION OF REPORT

Section II summarizes the pavement condition rating method and describes the computer program for performing calculations required to determine the PCI.

Section III summarizes information collected during field visits to Air Force bases in FY77 and the major command engineers' workshop.

Section IV provides guidelines for evaluating the condition of an airfield pavement feature. These guidelines were developed based on information described in Section III and further research.

Section V contains guidelines for selecting M&R alternatives based on results of pavement evaluation.

Section VI contains a procedure for performing economic analyses of M&R alternatives.

Section VII describes an example application of the guidelines and procedures presented in Sections IV, V, and VI.

Section VIII summarizes the report and provides conclusions and recommendations.

The results of the feasibility study to select an approach for determining the consequences of various M&R alternatives are presented as Appendix A in Volume IV. They were not included in this volume since it was decided, for the user's convenience, to limit the contents of this volume to information ready for field implementation.

All the appendices for this volume are presented in Volume IV. They include the feasibility study of M&R consequences, PCI computer program description, development of environmental zones, questionnaires used in field visits, correlation of PCI and profile roughness, pavement features used in M&R workshop, weighted performance questionnaire, summary of PCI data for FY77, and economic analysis considering performance.

SECTION II

PAVEMENT CONDITION INDEX

DESCRIPTION

The Pavement Condition Index (PCI) is a numerical indicator of pavement condition directly related to the pavement's structural integrity (ability to resist fracture, distortion, and disintegration) and surface operational condition. The PCI is a function of the type, quantity, and severity of observable pavement distress. It can be expressed as follows:

$$PCI = C - \sum_{i=1}^{p} \sum_{j=1}^{m_i} a(T_i, S_j, D_{ij})\, F(t,d) \qquad \text{[Equation 1]}$$

where PCI = pavement condition index

C = a constant depending on desired maximum scale value

a( ) = deduct weighting value depending on distress type T_i, level of severity S_j, and density of distress D_{ij}

i = counter for distress types

j = counter for severity levels

p = total number of distress types for pavement type under consideration

m_i = number of severity levels on the i^{th} type of distress

F(t,d) = an adjustment factor for multiple distresses that vary with total summed deduct value (t) and number of deducts (d).

This equation can only be evaluated when distress and severity level definitions, deduct values, and adjustment factors have been defined as illustrated in Figure 1. These factors and their development are described in Volumes I and II. The development process was iterative, as shown in Figure 2. The loop refers to the nine field tests conducted in FY76 (see Section III). After each field test, the PCI procedure was evaluated and revised if necessary.

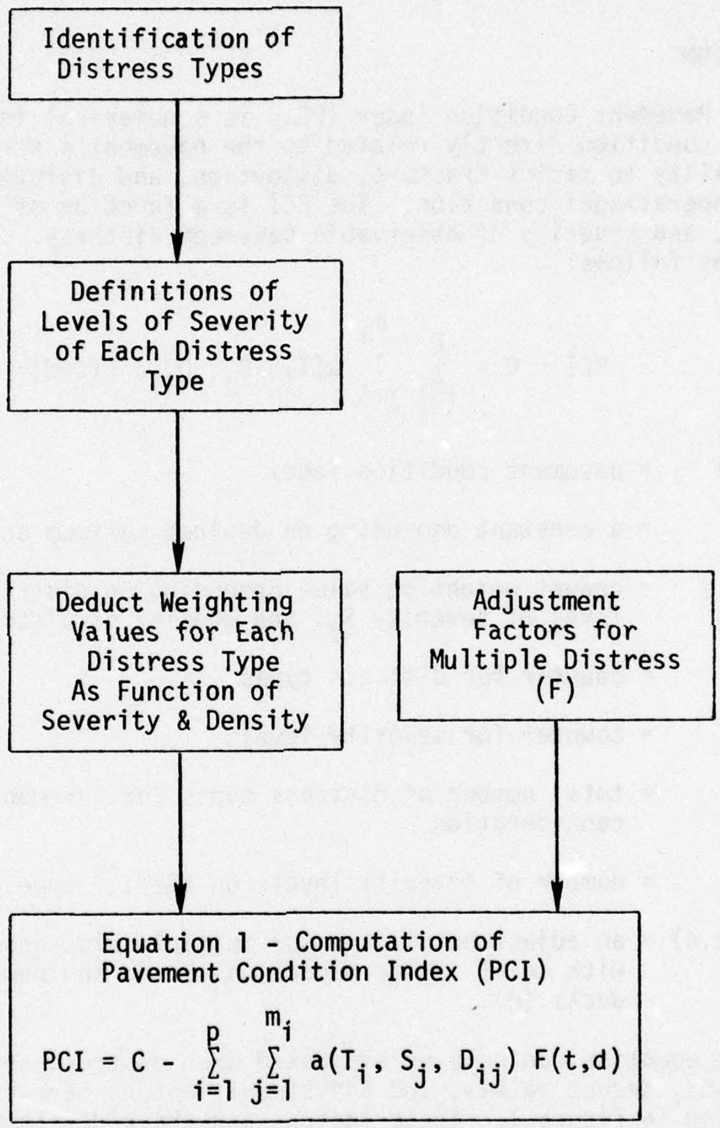


Figure 1. Information Needed to Determine the Pavement Condition Index Using Equation 1

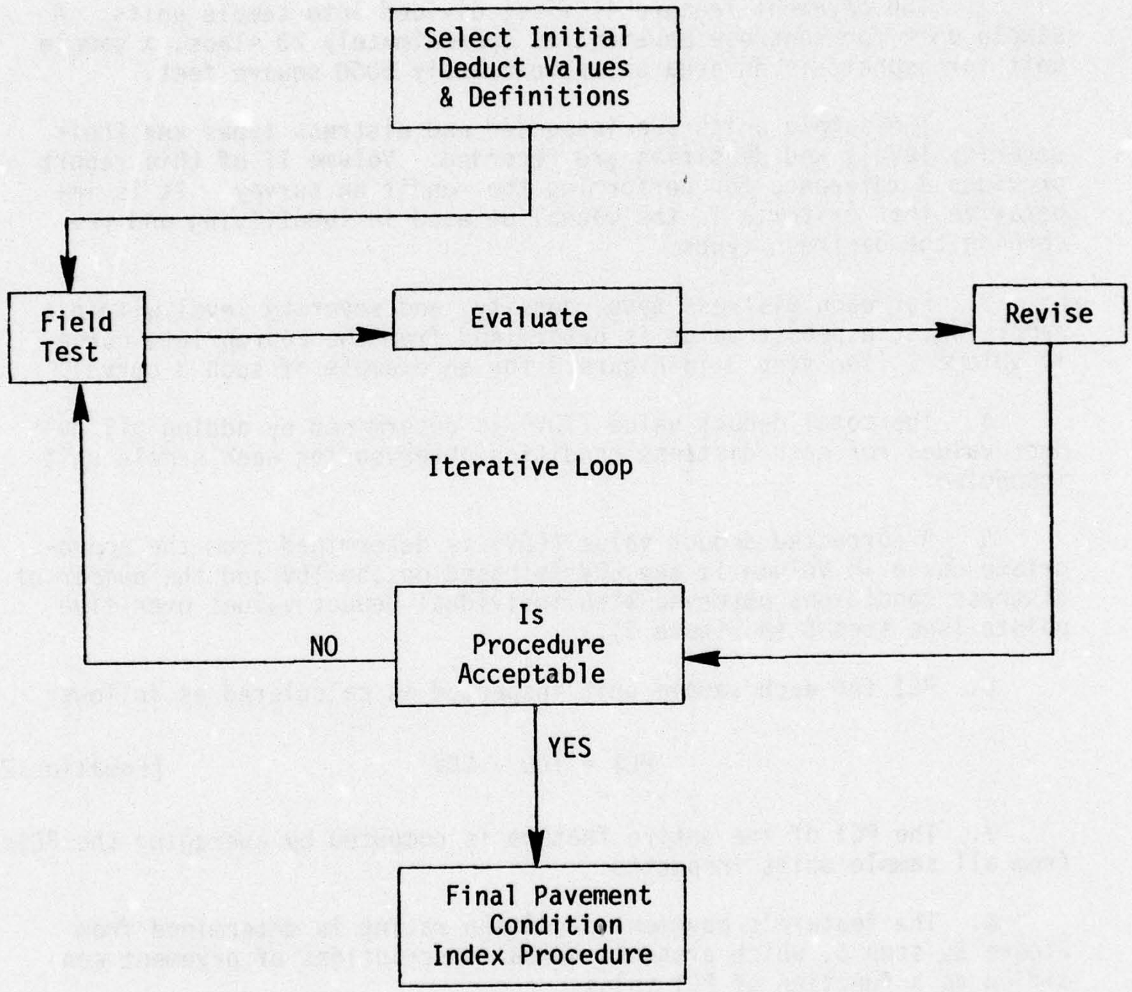


Figure 2. Iterative Procedure to Determine Realistic Distress Deduct Values and Distress Definitions Using a Subjective Approach

MANUAL CALCULATION OF THE PCI FOR A PAVEMENT FEATURE

A pavement feature is defined as a portion of pavement which (1) has consistent structural thickness and materials, (2) was constructed at one time, and (3) is located in one traffic area.

The PCI of a given pavement feature can be calculated manually by performing the following steps (Figure 3):

1. The pavement feature is first divided into sample units. A sample unit for concrete pavement is approximately 20 slabs; a sample unit for asphalt is an area of approximately 5000 square feet.

2. The sample units are inspected and distress types and their severity levels and densities are recorded. Volume II of this report provides a reference for performing the condition survey. It is imperative that criteria in the manual be used in identifying and recording the distress types.

3. For each distress type, density, and severity level within a sample unit, a deduct value is determined from the appropriate curve in Volume I (see step 3 in Figure 3 for an example of such a curve).

4. The total deduct value (TDV) is determined by adding all deduct values for each distress condition observed for each sample unit inspected.

5. A corrected deduct value (CDV) is determined from the appropriate curve in Volume I; the CDV is based on the TDV and the number of distress conditions observed with individual deduct values over five points (see step 5 in Figure 3).

6. PCI for each sample unit inspected is calculated as follows:

$$PCI = 100 - CDV \qquad \text{[Equation 2]}$$

7. The PCI of the entire feature is computed by averaging the PCIs from all sample units inspected.

8. The feature's pavement condition rating is determined from Figure 3, step 8, which presents verbal descriptions of pavement condition as a function of PCI value.

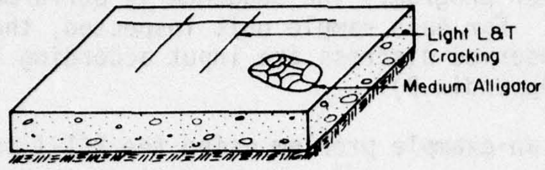
Appendix A and Section VII of Volume I provide more detailed information on the inspection procedure.

PCI-1 COMPUTER PROGRAM

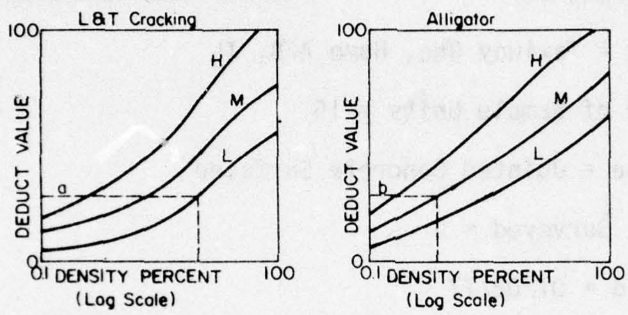
Computing the PCI manually is a simple operation for a single sample unit; however, the volume of data generated from a survey of an entire airfield is quite large, and calculations involving these data are

STEP 1. DIVIDE PAVEMENT FEATURE INTO SAMPLE UNITS.

STEP 2. INSPECT SAMPLE UNITS: DETERMINE DISTRESS TYPES AND SEVERITY LEVELS AND MEASURE DENSITY.

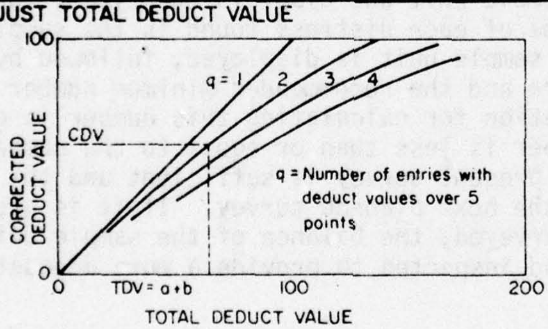


STEP 3. DETERMINE DEDUCT VALUES



STEP 4. COMPUTE TOTAL DEDUCT VALUE (TDV) a+b

STEP 5. ADJUST TOTAL DEDUCT VALUE



STEP 6. COMPUTE PAVEMENT CONDITION INDEX (PCI)=100-CDV FOR EACH SAMPLE UNIT INSPECTED.

STEP 7. COMPUTE PCI OF ENTIRE FEATURE (AVERAGE PCI'S OF SAMPLE UNITS).

STEP 8. DETERMINE PAVEMENT CONDITION RATING OF FEATURE.

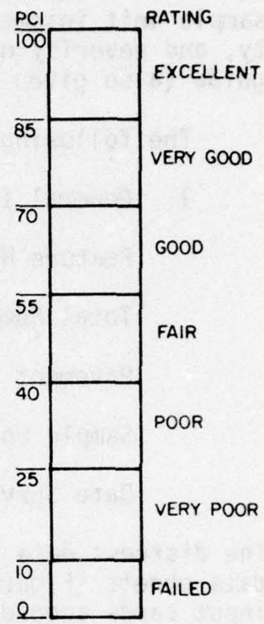


Figure 3. Steps for Determining PCI of a Pavement Feature

time-consuming. Therefore, a computer program named PCI-1 has been developed to aid in the calculation of the PCI. The PCI-1 program is written in COBOL for use on the Burroughs 3500 and Control Data Corporation (CDC) 6600 computers. The required field length for program execution on the CDC 6600 computer is 30,000 words. A flow chart of the program is shown in Appendix B.

The sequence for calculating the PCI manually is the basic sequence followed in the computer program. The sequence is performed on each sample unit inspected. For each sample unit inspected, the type, quantity, and severity of observed distress are input according to the input guide (also given in Appendix B).

The following is an example problem using the PCI-1 program:

1. General Information

   Feature Name = Taxiway One, Home AFB, IL

   Total Number of Sample Units = 15

   Pavement Type = Jointed Concrete Surfaced

   Sample Units Surveyed = 5

   Date Surveyed = 01/02/77

The distress data for the feature were measured and entered on survey data sheets (Figure 4). This information was then transferred to the input cards according to the guidelines shown in Appendix B. Figure 5 shows the input for this example problem. Figure 6 shows the output, which identifies each sample unit and displays the types, quantity, density, and deduct value of each distress found in the sample unit. The calculated PCI for each sample unit is displayed, followed by the combined PCI for the feature and the recommended minimum number of samples to be surveyed (the equation for calculating this number is given in Volume I). If this number is less than or equal to the number of samples to be surveyed, the present survey is sufficient and the number can be used as a guide for the next planned survey. If it is greater than the number of samples surveyed, the balance of the sample units should be selected at random and inspected to provide a more adequate estimate of the feature's PCI.

JOINTED CONCRETE PAVEMENT
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

AIRFIELD HOME AFB, IL FEATURE TAXIWAY ONE

DATE 01/02/77 SAMPLE UNIT 2

SURVEYED BY SK SLAB SIZE 20 x 20

	1	2	3	4
10	10L	3L 10L		
9	6L 10L	10L		
8	6L 10L	12M ~~10L~~		
7	10L	10L		
6	3L 10L	3L 10L		
5	10L	3L 10L		
4	10L	3L 10L		
3	3L 10L	10L		
2	3L 10L	2L 10L		
1	2L 10L	2L 10L		

1. Blow-Up
2. Corner Break
3. Longitudinal/ Transverse/ Diagonal Crack
4. "D" Crack
5. Joint Seal Damage
6. Patching, < 5 ft^2
7. Patching/ Utility Cut
8. Popouts
9. Pumping
10. Scaling/Map Crack/Crazing
11. Settlement Fault
12. Shattered Slab
13. Shrinkage Crack
14. Spalling -- Joints
15. Spalling -- Corner

DIST. TYPE	SEV.	NO. SLABS	% SLABS	DEDUCT VALUE
2	L	3		
3	L	6		
6	L	2		
10	L	19		
12	M	1		
13	L	1		
DEDUCT TOTAL				
CORRECTED DEDUCT VALUE (CDV)				

PCI = 100 − CDV = ______

RATING = ______

Figure 4. Field Data Sheets for Example Problem

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JOINTED CONCRETE PAVEMENT
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

AIRFIELD HOME FEATURE TAXIWAY ONE

DATE 01/02/77 SAMPLE UNIT 3

SURVEYED BY SK SLAB SIZE 20 X 20

	1	2	3	4
10	2L 10L	2L 10L		
9	2L 10L	12L		
8	2L 10L	12L 10L		
7	2L 10L	3H 10L		
6	3M 10L	3H 10L		
5	3M 10L	10L		
4	3M 10L	10L		
3	10L	10L		
2	10L	10L		
1	10L	3L 10L		

1. Blow-Up
2. Corner Break
3. Longitudinal/ Transverse/ Diagonal Crack
4. "D" Crack
5. Joint Seal Damage
6. Patching, < 5 ft^2
7. Patching/ Utility Cut
8. Popouts
9. Pumping
10. Scaling/Map Crack/Crazing
11. Settlement Fault
12. Shattered Slab
13. Shrinkage Crack
14. Spalling -- Joints
15. Spalling -- Corner

DIST. TYPE	SEV.	NO. SLABS	% SLABS	DEDUCT VALUE
2	L	5		
3	L	1		
3	M	3		
3	H	2		
10	L	20		
12	L	2		

DEDUCT TOTAL

CORRECTED DEDUCT VALUE (CDV)

PCI = 100 − CDV =

RATING =

Figure 4. Field Data Sheets for Example Problem (continued)

JOINTED CONCRETE PAVEMENT
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

AIRFIELD HOME FEATURE TAXIWAY ONE

DATE 01/02/77 SAMPLE UNIT 5

SURVEYED BY SK SLAB SIZE 20 X 20

	1	2	3	4
10	2L 10L	2L 10L		
9	2L 10L	2L 10L		
8	2L 10L	2L 10L		
7	2L 10L	2L 10L		
6	10L	2L 10L		
5	10L	10L		
4	10L	10L		
3	10L	10L		
2	10L	10L		
1	10L	10L		

1. Blow-Up
2. Corner Break
3. Longitudinal/ Transverse/ Diagonal Crack
4. "D" Crack
5. Joint Seal Damage
6. Patching, < 5 ft^2
7. Patching/ Utility Cut
8. Popouts
9. Pumping
10. Scaling/Map Crack/Crazing
11. Settlement Fault
12. Shattered Slab
13. Shrinkage Crack
14. Spalling -- Joints
15. Spalling -- Corner

DIST. TYPE	SEV.	NO. SLABS	% SLABS	DEDUCT VALUE
2	L	9		
10	L	20		

DEDUCT TOTAL

CORRECTED DEDUCT VALUE (CDV)

PCI = 100 − CDV =

RATING =

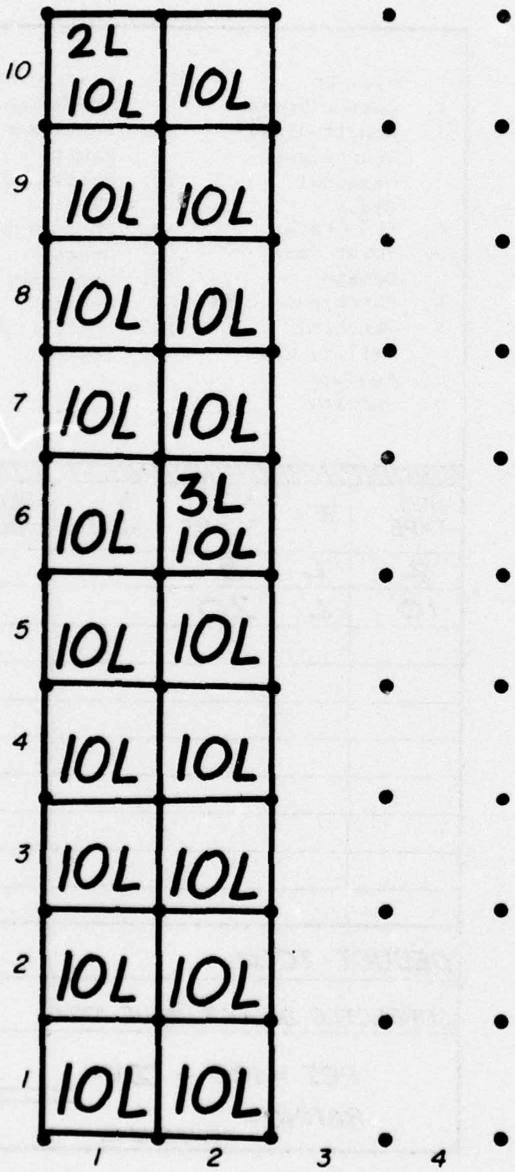
Figure 4. Field Data Sheets for Example Problem (continued)

JOINTED CONCRETE PAVEMENT
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

AIRFIELD HOME FEATURE TAXIWAY ONE

DATE 01/02/77 SAMPLE UNIT 7

SURVEYED BY SK SLAB SIZE 20 X 20



1. Blow-Up
2. Corner Break
3. Longitudinal/ Transverse/ Diagonal Crack
4. "D" Crack
5. Joint Seal Damage
6. Patching, < 5 ft^2
7. Patching/ Utility Cut
8. Popouts
9. Pumping
10. Scaling/Map Crack/Crazing
11. Settlement Fault
12. Shattered Slab
13. Shrinkage Crack
14. Spalling -- Joints
15. Spalling -- Corner

DIST. TYPE	SEV.	NO. SLABS	% SLABS	DEDUCT VALUE
2	L	1		
3	L	1		
10	L	20		

DEDUCT TOTAL

CORRECTED DEDUCT VALUE (CDV)

PCI = 100 − CDV =

RATING =

Figure 4. Field Data Sheets for Example Problem (continued)

JOINTED CONCRETE PAVEMENT
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

AIRFIELD HOME FEATURE TAXIWAY ONE

DATE 01/02/77 SAMPLE UNIT 9

SURVEYED BY SK SLAB SIZE 20X20

	1	2	3	4
10	2L 10L	2M 10L		
9	2L 10L	6L 10L		
8	10L	10L		
7	10L	10L		
6	10L	10L		
5	10L	10L		
4	10L	10L		
3	10L	10L		
2	10L	10L		
1	10L	10L		

1. Blow-Up
2. Corner Break
3. Longitudinal/ Transverse/ Diagonal Crack
4. "D" Crack
5. Joint Seal Damage
6. Patching, < 5 ft^2
7. Patching/ Utility Cut
8. Popouts
9. Pumping
10. Scaling/Map Crack/Crazing
11. Settlement Fault
12. Shattered Slab
13. Shrinkage Crack
14. Spalling -- Joints
15. Spalling -- Corner

DIST. TYPE	SEV.	NO. SLABS	% SLABS	DEDUCT VALUE
2	L	2		
2	M	1		
6	L	1		
10	L	20		
DEDUCT TOTAL				
CORRECTED DEDUCT VALUE (CDV)				

PCI = 100 − CDV = ______

RATING = ______

Figure 4. Field Data Sheets for Example Problem (concluded)

INPUT FORM FOR PCI COMPUTATION PROGRAM

PAGE ____ OF ____

CARD ID (1–2)	FEATURE NAME (3–27)	DATE OF SURVEY MO (28–29)	DAY (30–31)	YR (32–33)	FEATURE SIZE (SF OR NMBR OF SLABS) (34–41)	NUMBER OF SAMPLE UNITS IN FEATURE (42–46)	ALLOWABLE ERROR (47–49)	PVT TYPE (50)
01	TAXIWAY ONE HOME AFB IL	01	02	77	300	15	5	R

CARD ID (1–2)	SAMPLE UNIT ID NUMBER (3–8)	SAMPLE SIZE (SF OR NMBR OF SLABS) (9–13)	RANDOM OR ADDITIONAL (14)
02	SAMP2	20	R

CARD ID (1–2)	DISTRESS CODE (3–4)	SEV (5)	QUANTITY (6–10)	DISTRESS CODE (11–12)	SEV (13)	QUANTITY (14–18)	DISTRESS CODE (19–20)	SEV (21)	QUANTITY (22–26)	DISTRESS CODE (27–28)	SEV (29)	QUANTITY (30–34)	DISTRESS CODE (35–36)	SEV (37)	QUANTITY (38–42)	DISTRESS CODE (43–44)	SEV (45)	QUANTITY (46–50)
03	02	L	3	03	L	6	06	L	2	10	L	19	[illegible]	[illegible]	1	13		1
03																		
03																		

CARD ID (1–2)	SAMPLE UNIT ID NUMBER (3–8)	SAMPLE SIZE (SF OR NMBR OF SLABS) (9–13)	RANDOM OR ADDITIONAL (14)
02	SAMP3	20	R

CARD ID (1–2)	DISTRESS CODE (3–4)	SEV (5)	QUANTITY (6–10)	DISTRESS CODE (11–12)	SEV (13)	QUANTITY (14–18)	DISTRESS CODE (19–20)	SEV (21)	QUANTITY (22–26)	DISTRESS CODE (27–28)	SEV (29)	QUANTITY (30–34)	DISTRESS CODE (35–36)	SEV (37)	QUANTITY (38–42)	DISTRESS CODE (43–44)	SEV (45)	QUANTITY (46–50)
03	02	L	5	03	L	1	03	M	3	03	H	2	10	L	20	12	L	2
03																		
03																		

CARD ID (1–2)	SAMPLE UNIT ID NUMBER (3–8)	SAMPLE SIZE (SF OR NMBR OF SLABS) (9–13)	RANDOM OR ADDITIONAL (14)
02	SAMP5	20	R

CARD ID (1–2)	DISTRESS CODE (3–4)	SEV (5)	QUANTITY (6–10)	DISTRESS CODE (11–12)	SEV (13)	QUANTITY (14–18)	DISTRESS CODE (19–20)	SEV (21)	QUANTITY (22–26)	DISTRESS CODE (27–28)	SEV (29)	QUANTITY (30–34)	DISTRESS CODE (35–36)	SEV (37)	QUANTITY (38–42)	DISTRESS CODE (43–44)	SEV (45)	QUANTITY (46–50)
03	02	L	9	10	L	20												
03																		
03																		

KEYPUNCH OPERATOR: PUNCH ONLY THOSE LINES THAT HAVE HANDWRITTEN DATA.

Figure 5. Input for Example Problem

CONTINUATION SHEET

PAGE ____ OF ____

CARD ID (1 2)	SAMPLE UNIT ID NUMBER (3 4 5 6 7 8)	SAMPLE SIZE (SF OR NMBR OF SLABS) (9 10 11 12 13)	RANDOM OR ADDITIONAL (14)
02	SAMP7	20	R

CARD ID (1 2)	DISTRESS CODE (3 4)	SEV (5)	QUANTITY (6 7 8 9 10)	DISTRESS CODE (11 12)	SEV (13)	QUANTITY (14 15 16 17 18)	DISTRESS CODE (19 20)	SEV (21)	QUANTITY (22 23 24 25 26)	DISTRESS CODE (27 28)	SEV (29)	QUANTITY (30 31 32 33 34)	DISTRESS CODE (35 36)	SEV (37)	QUANTITY (38 39 40 41 42)	DISTRESS CODE (43 44)	SEV (45)	QUANTITY (46 47 48 49 50)
03	02	L		03	L		10	L	20									
03																		
03																		

CARD ID (1 2)	SAMPLE UNIT ID NUMBER (3 4 5 6 7 8)	SAMPLE SIZE (SF OR NMBR OF SLABS) (9 10 11 12 13)	RANDOM OR ADDITIONAL (14)
02	SAMP9	20	R

CARD ID (1 2)	DISTRESS CODE (3 4)	SEV (5)	QUANTITY (6 7 8 9 10)	DISTRESS CODE (11 12)	SEV (13)	QUANTITY (14 15 16 17 18)	DISTRESS CODE (19 20)	SEV (21)	QUANTITY (22 23 24 25 26)	DISTRESS CODE (27 28)	SEV (29)	QUANTITY (30 31 32 33 34)	DISTRESS CODE (35 36)	SEV (37)	QUANTITY (38 39 40 41 42)	DISTRESS CODE (43 44)	SEV (45)	QUANTITY (46 47 48 49 50)
03	02	L	2	02	M	1	06	L	1	10	L	20						
03																		
03																		

CARD ID (1 2)	SAMPLE UNIT ID NUMBER (3 4 5 6 7 8)	SAMPLE SIZE (SF OR NMBR OF SLABS) (9 10 11 12 13)	RANDOM OR ADDITIONAL (14)
02			

CARD ID (1 2)	DISTRESS CODE (3 4)	SEV (5)	QUANTITY (6 7 8 9 10)	DISTRESS CODE (11 12)	SEV (13)	QUANTITY (14 15 16 17 18)	DISTRESS CODE (19 20)	SEV (21)	QUANTITY (22 23 24 25 26)	DISTRESS CODE (27 28)	SEV (29)	QUANTITY (30 31 32 33 34)	DISTRESS CODE (35 36)	SEV (37)	QUANTITY (38 39 40 41 42)	DISTRESS CODE (43 44)	SEV (45)	QUANTITY (46 47 48 49 50)
03																		
03																		
03																		

CARD ID (1 2)	SAMPLE UNIT ID NUMBER (3 4 5 6 7 8)	SAMPLE SIZE (SF OR NMBR OF SLABS) (9 10 11 12 13)	RANDOM OR ADDITIONAL (14)
02			

CARD ID (1 2)	DISTRESS CODE (3 4)	SEV (5)	QUANTITY (6 7 8 9 10)	DISTRESS CODE (11 12)	SEV (13)	QUANTITY (14 15 16 17 18)	DISTRESS CODE (19 20)	SEV (21)	QUANTITY (22 23 24 25 26)	DISTRESS CODE (27 28)	SEV (29)	QUANTITY (30 31 32 33 34)	DISTRESS CODE (35 36)	SEV (37)	QUANTITY (38 39 40 41 42)	DISTRESS CODE (43 44)	SEV (45)	QUANTITY (46 47 48 49 50)
03																		
03																		
03																		

KEYPUNCH OPERATOR: PUNCH ONLY THOSE LINES THAT HAVE HANDWRITTEN DATA.

Figure 5. Input for Example Problem (concluded)

FEATURE IDENTIFICATION : TAXIWAY ONE HOME AFB IL

DATE SURVEYED 05/01/78. RIGID PAVEMENT.

FEATURE SIZE : 00000300 SLABS

TOTAL NO OF SAMPLE UNIT : 15

ALLOWABLE ERROR WITH 95% CONFIDENCE : 5

SAMPLE UNIT ID : SAMP2
NO. OF SLABS IN SAMPLE : 20

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02	LOW	3	15.00	11.4
03	LOW	6	30.00	17.0
06	LOW	2	10.00	1.1
10	LOW	19	95.00	16.5
12	MEDIUM	1	5.00	19.3
13	LOW	1	5.00	1.0

PCI = 53

SAMPLE UNIT ID : SAMP3
NO. OF SLABS IN SAMPLE : 20

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02	LOW	5	25.00	18.0
03	LOW	1	5.00	4.9
03	MEDIUM	3	15.00	24.0
03	HIGH	2	10.00	26.0
10	LOW	20	100.00	17.0
12	LOW	2	10.00	17.8

PCI = 30

SAMPLE UNIT ID : SAMP5
NO. OF SLABS IN SAMPLE : 20

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02	LOW	9	45.00	27.0
10	LOW	20	100.00	17.0

PCI = 63

SAMPLE UNIT ID : SAMP7
NO. OF SLABS IN SAMPLE : 20

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02	LOW	1	5.00	4.0
03	LOW	1	5.00	4.9
10	LOW	20	100.00	17.0

PCI = 74

SAMPLE UNIT ID : SAMP9
NO. OF SLABS IN SAMPLE : 20

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02	LOW	2	10.00	8.0
02	MEDIUM	1	5.00	8.2
06	LOW	1	5.00	0.6
10	LOW	20	100.00	17.0

PCI = 75

NO. OF RANDOM SAMPLE : 5

NO. OF ADDITIONAL SAMPLE : 0

PCI OF FEATURE -TAXIWAY ONE HOME AFB IL = 59 RATING = GOOD

RECOMMENDED MINIMUM OF 14 RANDOM SAMPLE UNITS TO BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED: 18.5

ESTIMATED DISTRESS FOR FEATURE : TAXIWAY ONE HOME AFB IL

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02	LOW	60	20.00	15.0
02	MEDIUM	3	1.00	1.7
03	LOW	24	8.00	7.1
03	MEDIUM	9	3.00	7.5
03	HIGH	6	2.00	8.0
06	LOW	9	3.00	0.4
10	LOW	297	99.00	16.9
12	LOW	6	2.00	5.0
12	MEDIUM	3	1.00	5.0
13		3	1.00	0.4

FEATURE	PCI	RATING
TAXIWAY ONE HOME AFB IL	59	GOOD

Figure 6. Example Output

SECTION III

SUMMARY OF FIELD AND WORKSHOP DATA

FIELD DATA

Five major command airfields were visited as part of the FY77 work. Figure 7 shows these five bases along with the nine bases used for field validation of the condition rating procedure in FY76. This section summarizes the purpose of the visits and the data collected at each of the five bases. The commands visited were Strategic Air Command (SAC), Military Airlift Command (MAC), Tactical Air Command (TAC), Air Training Command (ATC), and Air Force Logistics Command (AFLC). At the MAC base, where an Air National Guard (ANG) unit was located, the pavements were surveyed in conjunction with the pavement engineer from the ANG Bureau.

The three major objectives of the field visits were (1) to accomplish a trial implementation of the survey procedure, (2) to collect survey data on many pavement features, and (3) to obtain condition survey data on some pavement features which have had current laser profiles taken of them.

The trial implementation phase was initiated at a meeting with the major command engineers and many other Air Force representatives in December 1976 at Tyndall AFB. It was decided that this implementation would provide a test of the ease of technology transfer. At all five bases the base engineer had little or no difficulty understanding and applying the new condition rating procedures. However, the following aids must be available to the base pavement engineer and other personnel to assist in implementing the procedure:

1. Airfield Pavement Distress Identification Manual--Volume II of this report (a slide presentation on distress identification was developed as an additional aid for use by the Air Force in training personnel).

2. Condition survey procedure, including inspection methods and deduct value curves.

3. Field training in conducting the condition survey. Field experience has shown that implementation of the new procedures poses no significant problems.

Another important finding of the trial implementation was that the new method generally takes less time than the existing Air Force survey procedures. In addition, the new method provides much more useful information.

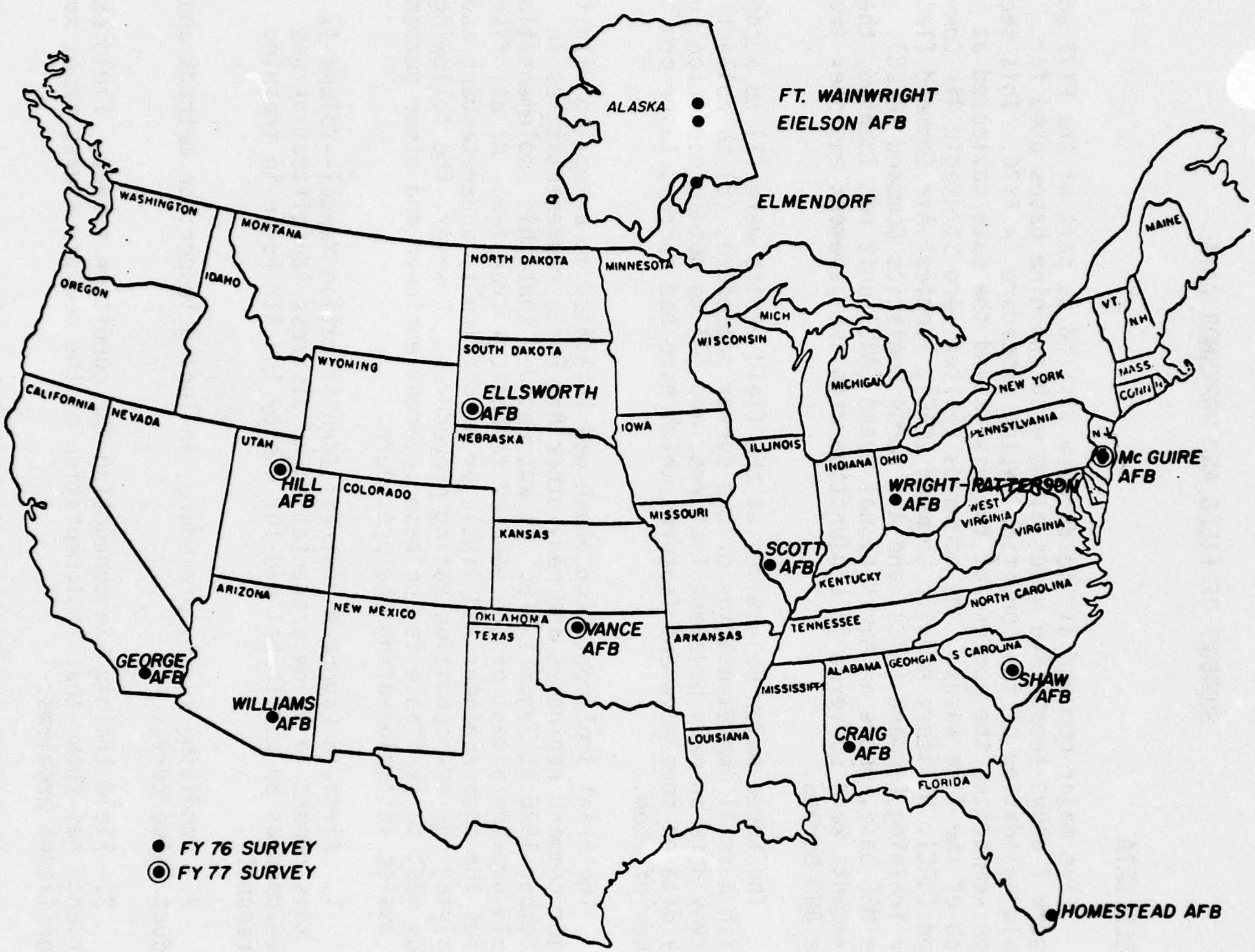


Figure 7. Airfields Surveyed for Testing and Validation of the Pavement Condition Index and Development of M&R Guidelines

The collection of condition survey data on entire features is an extension of the FY76 work correlating the PCI with M&R needs. The limited data collected in FY76 indicated that there was potential use for the PCI in determining M&R needs. Therefore, many in-service airfield features had to be surveyed and other information collected to provide the data base to establish a correlation.

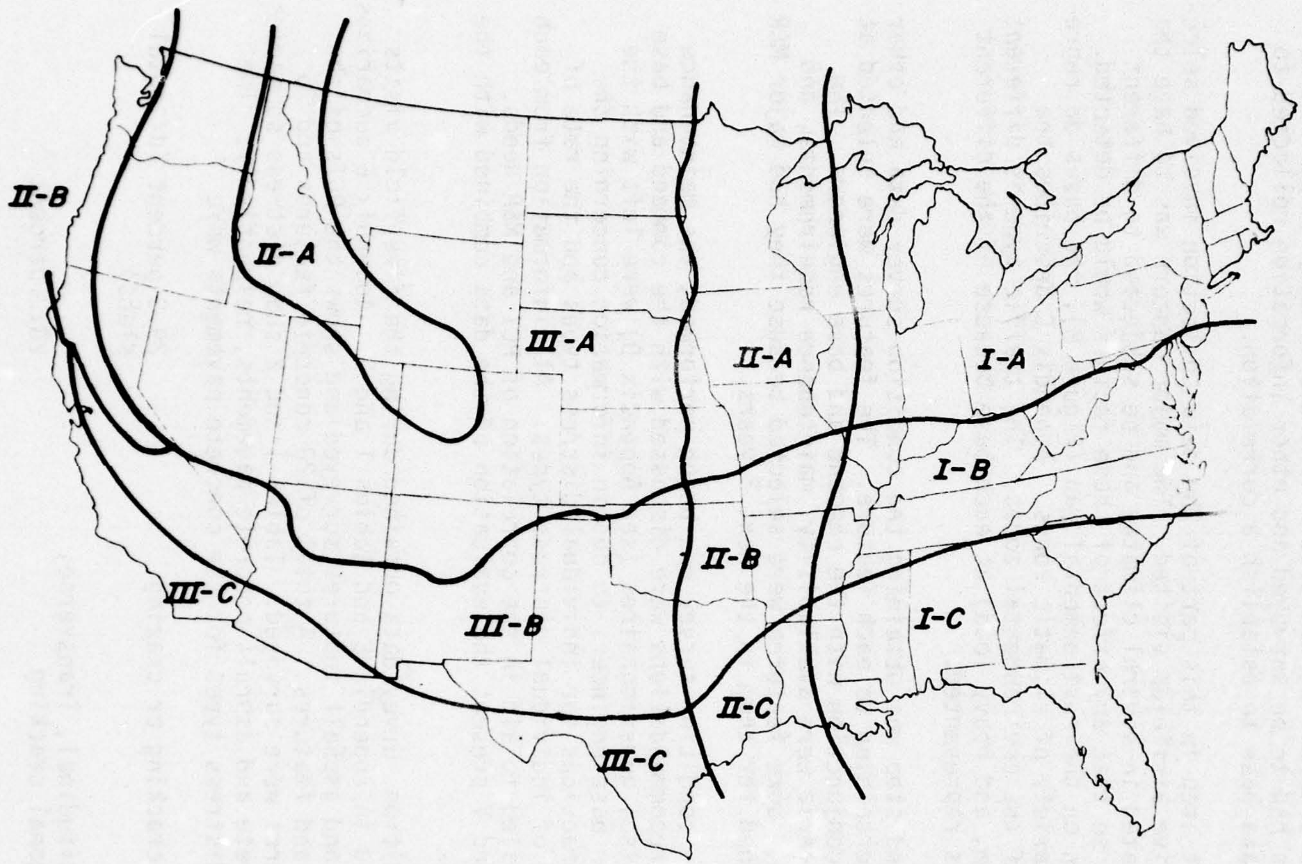
The first step in this part of the data collection involved selection of the five airfields visited. The major concern was to have the airfields located in several climates and be subjected to different traffic types so that any effect of these factors would be detected. As can be seen on the environmental map (Figure 8), the bases do represent a wide variety of climatic zones. Appendix C describes the development of the environmental zones. The traffic type is different (light, medium, and heavy load) at each base because of the different major commands represented.

The second step was obtaining the condition survey data and other information pertaining to each feature. The features were selected at each base in conjunction with the command and base engineers. The selection criteria were availability, maintenance requirements, and pavement type. Some features were selected because they had major M&R programs planned for them in the next 2 years.

While the condition survey was being performed, the maintenance policies and recommendations were discussed with the command and base engineers. Also, questionnaires (see Appendix D) were left with the command and/or base engineers to obtain information concerning the maintenance practices for individual distress types and the rate of deterioration of individual distress types. All information from each base was compiled to aid in the correlation of PCI and M&R needs. Sections IV and V present the evaluation of the data combined with the workshop data.

The condition survey data obtained during the five field visits are summarized in Appendix E and Tables 1 and 2. Appendix E summarizes the concrete and asphalt features surveyed and shows the PCIs of the sample units and features. A total of 28 concrete features and 25 asphalt features were surveyed. Tables 1 and 2 show distress summaries for the concrete and asphalt concrete pavements, respectively. The most common distress types for the concrete pavements were

1.	Map cracking or crazing	29.9 percent (of total slabs)
2.	Longitudinal, Transverse, Diagonal cracking	28.2 percent
3.	Shrinkage cracks	12.5 percent
4.	Patches less than 5 square feet	9.8 percent



A = LOW TEMPERATURE
B = FREEZE-THAW
C = HIGH TEMPERATURE

I = SOIL IS WET ALL YEAR AROUND
II = SOIL IS WET FOR ONLY A PART OF THE YEAR.
III = SOIL IS DRY ALL YEAR AROUND

Figure 8. Environmental Zones of Pavement Influence

TABLE 1. CONCRETE PAVEMENT DISTRESS SUMMARY

Distress Type	Base 1	Base 2	Base 3	Base 4	Base 5	Totals
	590[a]	1576	385	1112	708	4371
Blow-up	0.0	0.0	0.0	0.0	0.0	0.0
Corner break	1.2[b]	0.90	0.26	1.8	0.0	0.968
Longitudinal/ transverse/diag. cracking	36.8	38.2	0.78	28.1	13.8	28.2
"D" cracking	0.7	15.7	0.0	12.1	0.71	8.9
Joint seal damage	c	c	c	c	c	c
Patching < 5 square feet	23.9	5.90	11.7	11.2	3.7	9.83
Patching/ utility cut	8.5	0.60	1.8	2.4	0.85	2.27
Popouts	0.0	0.0	0.0	0.0	0.14	0.023
Pumping	0.0	0.0	0.0	0.0	0.0	0.0
Scaling/map crack/crazing	62.8	34.1	19.7	10.2	29.7	29.91
Settlement/fault	3.7	0.06	0.0	0.5	0.85	0.786
Shattered/slab	1.02	0.5	0.0	2.4	0.14	0.987
Shrinkage crack	0.16	4.1	12.2	34.9	6.2	12.46
Spalling, joints	2.03	0.9	1.8	10.3	3.0	3.86
Spalling, corner	3.20	0.95	4.7	19.7	5.1	7.03

[a] Total number of slabs included in survey at named base.
[b] Percent slabs containing each distress type.
[c] This distress not determined on a slab by slab basis.

TABLE 2. ASPHALT PAVEMENT DISTRESS SUMMARY

Distress type	Base 1	Base 2	Base 3	Base 4	Base 5	Totals
	250,000[a]	262,000	317,500	138,000	338,625	1,306,625
Alligator Cracking	21.15[b]	0.798	9.31	0.330	0.937	6.75
Bleeding	0.0	0.0	0.0	0.0	0.047	0.012
Block Cracking	27.0	11.62	0.0	0.0	6.64	9.22
Corrugation	0.0	0.0	0.0	0.0	0.0	0.0
Depression	0.223	0.0	0.015	0.0	0.103	0.079
Jet Blast	0.0	0.0	0.0	0.0	0.0	0.0
Joint reflection *from PCC*	0.0[c]	0.571[c]	3.44[c]	15.96[c]	2.07[c]	4.06[c]
Longitudinal and transverse cracking	1.03[c]	3.64[c]	1.47[c]	0.219	2.50[c]	[illegible]
Oil spillage	0.0	0.0	0.003	0.0	0.077	0.021
Patching	0.763	0.149	0.015	0.087	0.183	0.236
Polished aggregate	0.0	0.0	0.0	0.0	0.0	0.0
Raveling/ weathering	6.01	0.152	2.58	9.5	0.513	2.94
Rutting	2.99	0.243	3.01	0.0	0.258	1.42
Shoving from PCC	0.018	0.0	0.0	0.0	0.0	0.003
Slippage cracking	0.0	0.078	0.0	0.012	0.0	0.028
Swelling	0.0	0.0	0.023	0.0	0.053	0.019

[a] Total square footage of pavement surveyed at base.

[b] Percent area of each distress of total area (except for those labeled "c").

[c] (linear feet of crack/100 square feet) x 100.

5. Durability cracking 8.9 percent

6. Corner spalls 7.0 percent

The most common distress types for the asphalt concrete sections surveyed were:

1. Block cracking 9.2 percent (of total area)

2. Alligator cracking 6.7 percent

3. Joint reflection cracking 4.1 percent

4. Raveling/weather 2.9 percent

5. Long. and trans. cracking 2.0 percent

6. Rutting 1.4 percent

The third objective (correlating PCI or PCI components with laser profilometer data) was accomplished at two of the five bases. A total of three concrete and four asphalt concrete features were used in this analysis. The results obtained from these data are given in Section IV and Appendix F.

MAJOR COMMAND WORKSHOP

While the field visits were used to gather individuals' opinions on M&R topics, the workshop was used to gather collective information from the major command engineers. The following three areas were emphasized during the workshop:

1. M&R practices for individual distress types.

2. M&R recommendations for entire features.

3. Economic analysis using performance weighting factors.

A brief discussion on the data collection for each of these topics is given in the following paragraphs. The analysis of the data is given throughout Sections IV, V, and VI.

MAINTENANCE AND REPAIR FOR INDIVIDUAL DISTRESS

This portion of the workshop was used to obtain acceptable M&R methods for individual distress types. Most of the questionnaires given to the command engineers on the field visits (see Appendix D, Questionnaire no. 5) were returned prior to the workshop. The individual answers were then summarized in tables for asphalt and concrete pavements. Copies of these tables were given to all attendees of the workshop as a basis for discussion. The ensuing session centered on two topics: (1) selection

of M&R methods to be used and (2) identification of the distress types and severities to which the methods were applicable. After lengthy discussions, the final tables for M&R types and corresponding distress types were finalized. These tables are shown in Section V.

MAINTENANCE RECOMMENDATIONS FOR FEATURES

Another outcome of the December 1976 meeting at Tyndall AFB was the decision that the tentative M&R zones developed in Section VIII of Volume I of this report should be further tested based on extensive additional data from entire features. As a result, the attendees of the workshop were asked to evaluate 37 airfield features (18 runway features, 11 taxiway features, and 8 apron features). The information on each feature was presented on the form shown in Figure 9. Appendix G provides the data sheets for the features. Along with this information, slides were shown which represented the typical distress(es) found in the feature. The M&R recommendations were obtained through the questionnaire shown in Figure 10. If strong disagreement between the attendees was voiced after the evaluation period, the feature M&R requirements were briefly discussed, and the attendees could then reevaluate their decisions.

The results obtained from the evaluation are presented in Section V, which contains the breakdown of raters recommending certain M&R categories for each feature. This information was utilized in the development of the M&R zones used in determining the feature's present M&R needs.

PERFORMANCE WEIGHTING FACTORS

A method of economic analysis employing the performance (PCI over time) of the pavement feature is developed in Appendix H. To employ the method, performance weighting factors for various pavement features had to be developed. Development of the performance factors was accomplished by obtaining subjective ratings of the satisfaction level for various pavement uses and types.

The attendees were given a brief explanation of the theory of the economic analysis method using performance weighting factors. They were then asked to fill out the questionnaire shown in Appendix G, which basically consists of a randomized listing of pavement types (runways, taxiways, aprons), pavement usage (primary, secondary), and pavement condition (excellent, very good, etc.). For each combination of pavement type, use, and condition, the attendees were asked to give the pavement a satisfactory rating. In this case, satisfaction was measured on a scale of 0 to 1, with 0 representing totally unsatisfactory and 1 representing total satisfaction. The performance weighting factor was obtained by subtracting the satisfaction from 1. An in-depth explanation of the scale is given in Appendix H, along with the results of the satisfaction ratings.

I. FEATURE INFORMATION

Feature Type: ____________________ Environmental: ____________

Construction Date: ________________ Conditions: ____________

Overlay Date: ____________________ Pavement Type: ____________

Traffic Area: ____________________ Feature Dimensions: ____________

Primary Aircraft: ____________________

PAVEMENT STRUCTURE	AVAILABLE PROPERTIES

DISTRESS SUMMARY
(Average Quantity Over Entire Feature)

DISTRESS TYPE	SEVERITY	QUANTITY	DENSITY %

Figure 9. Feature Maintenance and Repair Evaluation

FEATURE MAINTENANCE AND REPAIR
EVALUATION CONT.

II QUESTIONNAIRE

Answer all the following questions based on the information given in part I and the slides you have just seen pertaining to the feature.

1. Considering all information given for this feature which types of maintenance and repair activities would you apply to the pavement within the next two years?

a. Do Nothing ____________________
b. Crackfilling of ____________________
c. Joint Sealing ____________________
d. Fog Seal of ____________________
e. Slurry Seal of ____________________
f. Shallow Patch of ____________________
g. Deep Patch of ____________________
h. Slab Replacement of ____________________
i. Heater Planning of ____________________
j. Apply and Roll Sand Coat to ____________________
k. Reprocessing
l. Overlay
m. Reconstruct
n. Apply Rejuvenator to ____________________
o. Surface Leveling of ____________________
p. Undersealing of ____________________
q. Slab grinding of ____________________
r. Slab Jacking (grout) ____________________
s. Other explain ____________________

2. How would you classify the maintenance and repair activities previously chosen?

a. Preventive
b. Localized
c. Major Localized
d. Overall
e. Other explain ____________________

Figure 10. Questionnaire on Feature M&R.

SECTION IV

CONDITION EVALUATION OF A PAVEMENT FEATURE

GENERAL

The first step in determining optimum maintenance and repair for any given pavement feature is an accurate and comprehensive evaluation of the existing condition of the pavement.

Airfield pavement condition depends on several factors which can be called condition indicators. Comprehensive pavement condition evaluation requires measurement of these condition indicators, which include at least the following:

1. Operational Surface Indicators

    a. Roughness (both localized and profile roughness)
    b. Skid Resistance/hydroplaning potential
    c. Foreign Object Damage (FOD) Potential

2. Structural Indicators

    a. Structural Integrity

        Cracking
        Distortion
        Disintegration

    b. Load Carrying Capacity

3. Other Indicators

    a. Rate of Deterioration
    b. Amount of Previous M&R applied

Many of these condition indicators are interrelated; for example, surface distortion and disintegration are related to surface roughness. A complete condition evaluation requires consideration of each condition index individually and all the indicators collectively.

Most of the pavement condition indicators previously listed are related to observable pavement distress, as shown in Figure 11 (for asphalt-surfaced pavements) and 12 (for jointed concrete pavements). In most cases the observable pavement distress gives a good indication of pavement condition; FOD potential, structural integrity, roughness (short wave lengths), and rate of deterioration can be determined in this manner. In a few cases this is not so; e.g., the skid resistance/hydroplaning potential of concrete-surfaced pavements is not so detectable. Measurement of some of these condition indicators, such as surface roughness,

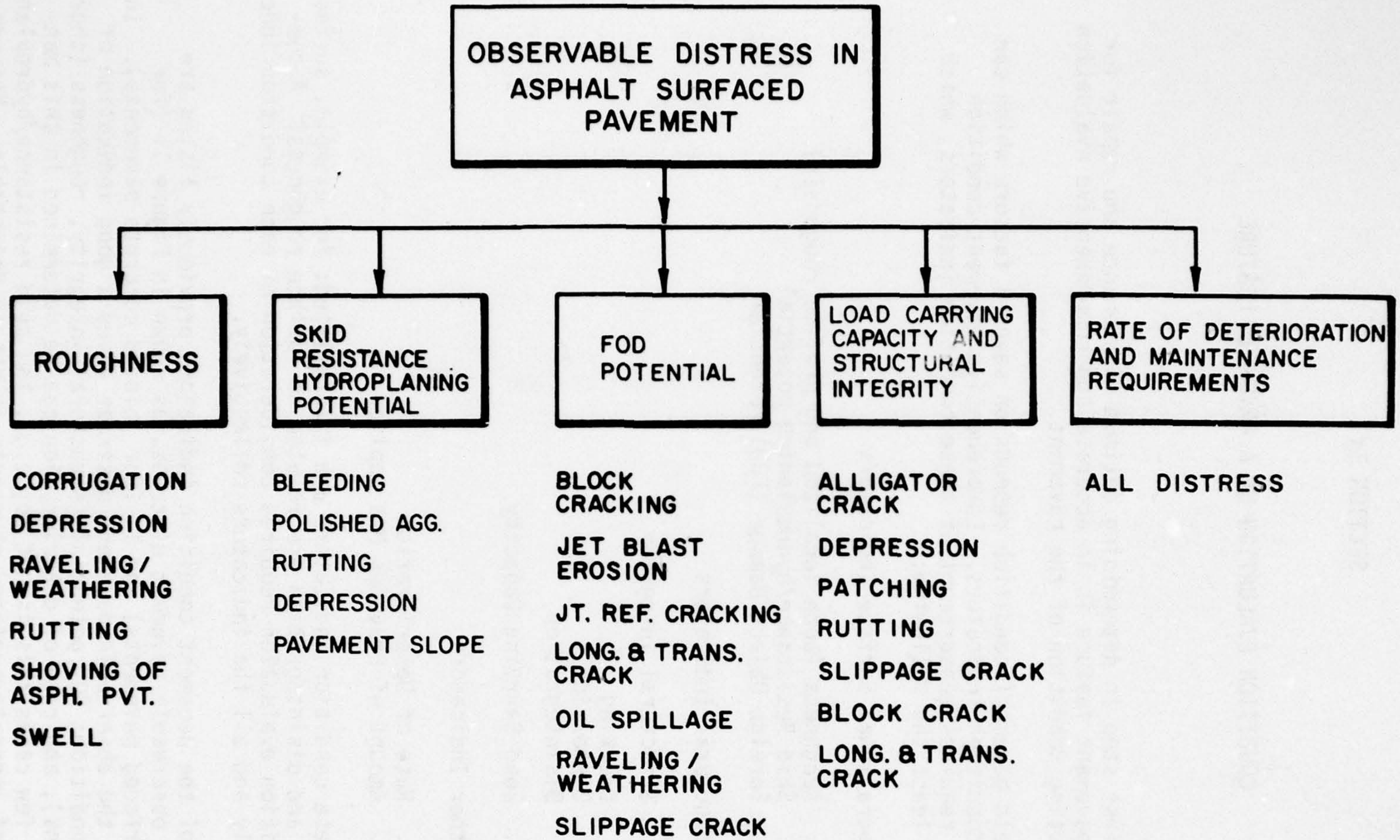


Figure 11. Relationship of Observable Distress in Asphalt-Surfaced Pavements to Various Pavement Condition Indicators

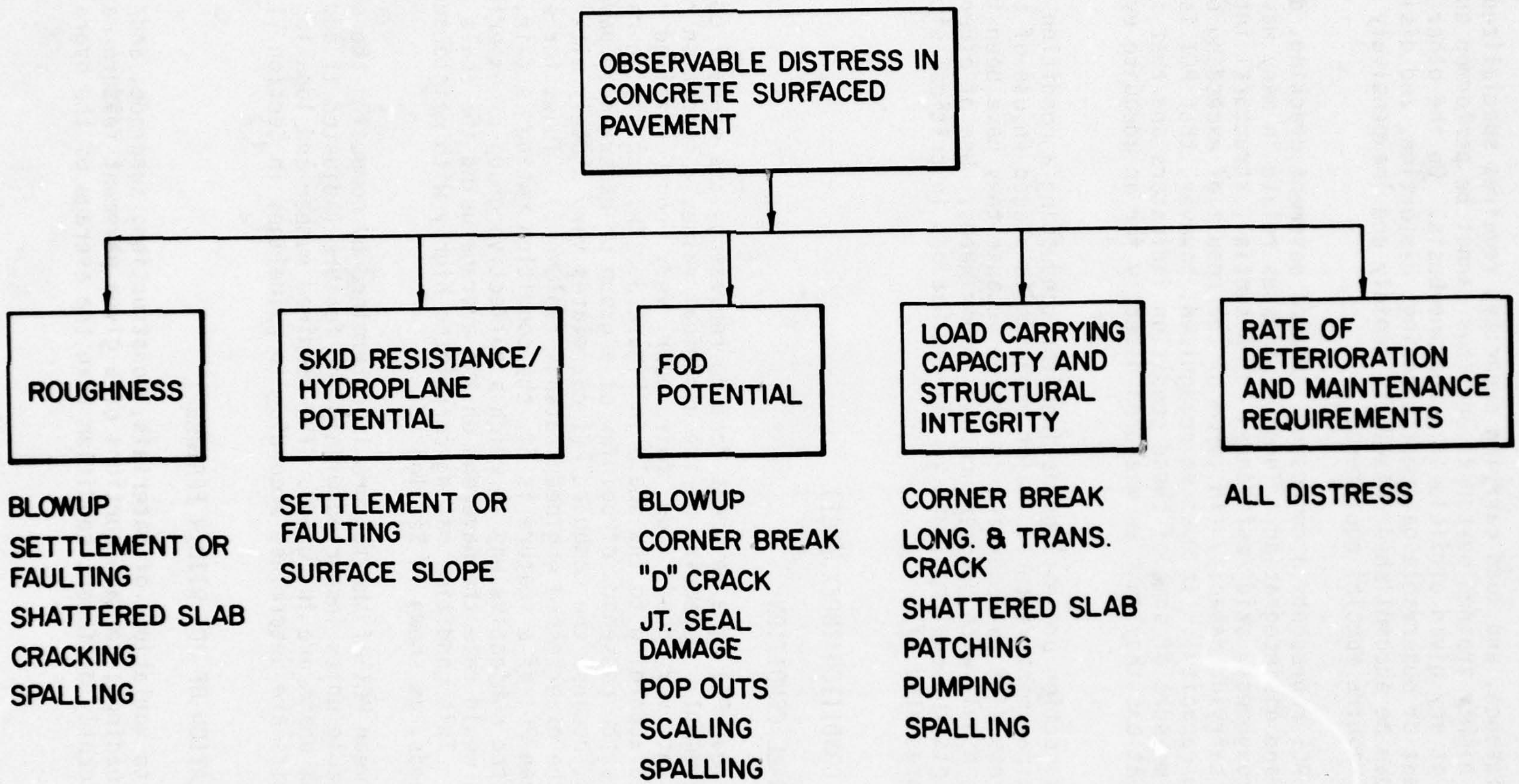


Figure 12. Relationship of Observable Distress in Concrete-Surfaced Pavements to Various Pavement Condition Indicators

skid resistance, and load carrying capacity, requires specialized equipment and highly trained personnel and thus cannot be performed on all features at any given airfield on a routine basis. On the other hand, measurement of observable pavement cracking, distortion, and disintegration can be accomplished relatively rapidly and inexpensively and does not require special equipment.

The PCI represents a composite index of pavement cracking, distortion, and disintegration. These distresses relate in many ways to surface roughness, skid resistance, FOD potential, structural integrity, and load carrying capacity (in terms of the result of exceeding or not exceeding capacity). It must be recognized, however, that PCI is not a direct measure of some of these condition indicators and that in certain situations they must be measured directly for an adequate evaluation.

This section presents guidelines for conducting a condition evaluation of a pavement feature. Major emphasis is placed on use of the PCI and distress data to determine condition because they have been found to correlate highly with maintenance and repair needs. Use of other direct measurements to supplement and verify evaluations in critical situations is also presented.

PAVEMENT CONDITION INDEX (PCI)

OVERALL CONDITION

The mean PCI of a pavement feature represents the overall condition of the pavement. Depending on its numerical value, a condition rating of excellent, very good, good, fair, poor, very poor, or failed can be determined according to the scale in Figure 3. This condition rating represents the consensus of opinion of a group of experienced pavement engineers, because the computed PCI correlates very closely with the mean of the experienced engineer ratings (Volume I). Thus, for example, if the mean PCI of a feature is 50, the condition rating is fair, which is the subjective way in which a collective group of experienced engineers would rate the pavement on the average using the scale in Figure 3. This condition rating correlates highly with maintenance and repair needs, as shown in Section V.

The mean PCI of the feature is determined by computing the average of all sample units inspected within the feature (adjusted if additional non-ramdom units are included). The required number and location of sample units are determined according to guidelines in Section VII of Volume I.

VARIATION OF PCI WITHIN FEATURE

Due to variations of materials, construction, subgrade, and/or traffic loadings, certain portions of a given pavement feature may show a significantly different condition than the average of the overall

feature. Areas having a poorer condition are of major concern. Variation within a feature occurs on both a localized random basis (i.e., from material variability), and a systematic basis (i.e., from traffic patterns).

Random localized variation occurs when a relatively small localized area within a feature varies significantly in condition from the normal. For example, consider a taxiway feature 2500 feet long and 50 feet wide constructed with jointed concrete. The feature contains a total of 10 sample units, all of which were inspected. The PCIs of each are as follows:

1. 60	6. 23
2. 64	7. 61
3. 74	8. 58
4. 74	9. 70
5. 28	10. 80

The mean PCI of the feature is 59, which gives it a good condition rating. However, two of the inspection units have poor and very poor condition ratings, and three have very good condition ratings. This variation can be illustrated by computing the percentage of area of the feature within each condition rating as follows:

Excellent	0 percent
Very Good	30 percent
Good	50 percent
Fair	0 percent
Poor	10 percent
Very Poor	10 percent
Failed	0 percent

Figure 13 is a plot of the PCI of each sample unit along the longitudinal profile. The highly variable condition caused by the localized area of poor-very poor condition is obvious.

The random variation in the PCIs of sample units within features at the many airfields surveyed over the past 3 years was analyzed. Tables 3 and 4 give the mean PCI, standard deviation, and coefficient of variation of PCI for all features surveyed. Plots of standard deviation and coefficient of variation versus mean PCI are given in Figures 14 and 15 for asphalt-surfaced pavements. There is a definite correlation between

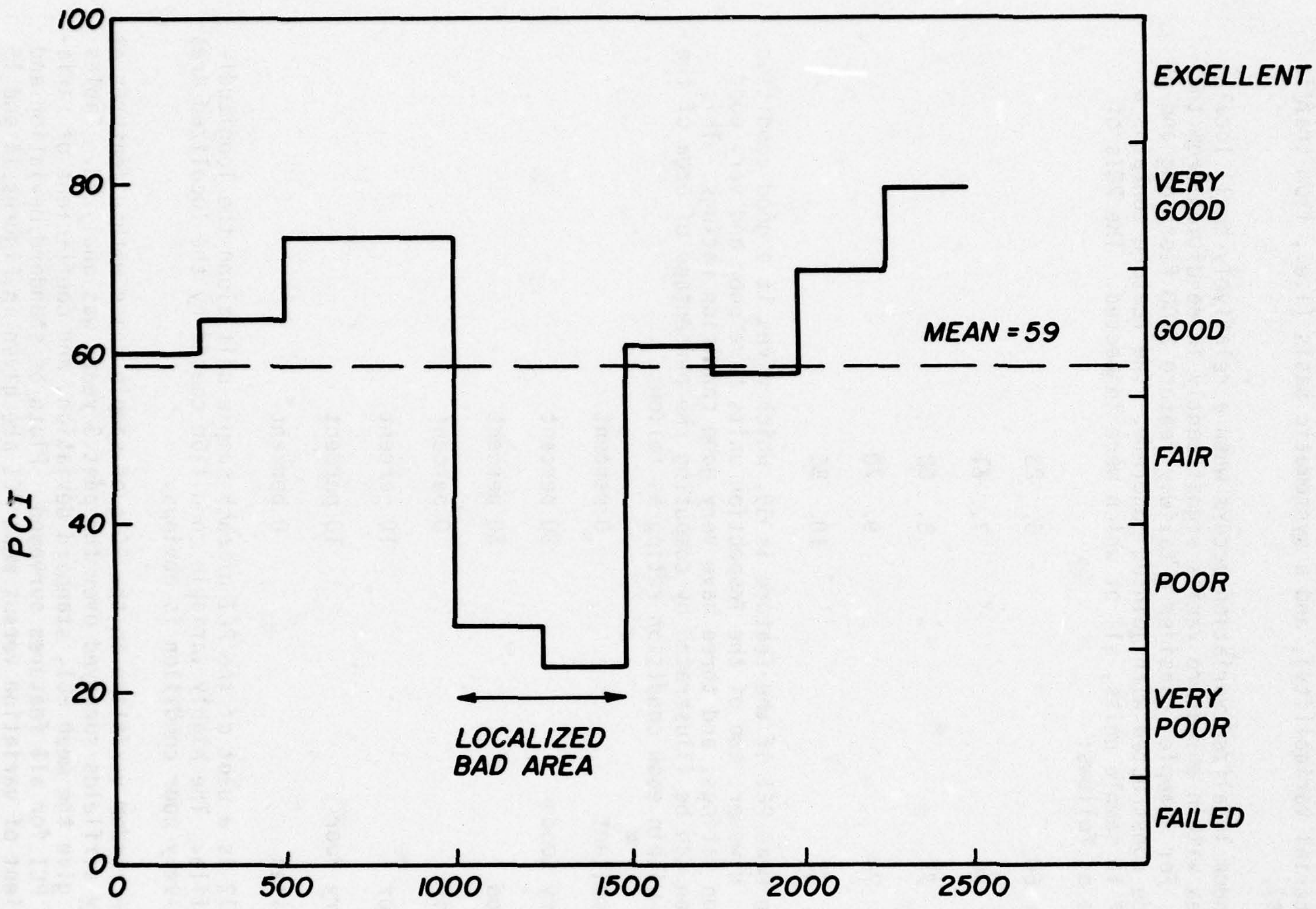


Figure 13. Illustration of Longitudinal Variation in Condition Along Taxiway

TABLE 3. SUMMARY OF PCI FEATURE DATA FOR CONCRETE-SURFACED PAVEMENT

Feature	No. Samples	Mean PCI	Std. Dev.	Range	COV
Scott-AP	3	56	19	35-72	34
HM-TW	5	60	19	28-74	32
HM-RW	6	83	20	51-98	24
WR-RW	3	36	19	23-57	53
McG-TW	8	32	8	22-47	25
McG-TW	10	32	12	16-61	38
McG-TW	7	68	13	45-85	19
McG-RW	7	42	20	22-79	48
Will-RW	28	59	16	30-85	27 (cent. 4 slabs)
EL-RW	4	79	4	75-85	5
EL-RW	4	80	7	72-88	9
EL-RW	4	89	5	83-93	6
EL-RW	4	85	7	78-92	8
VA-RW	7	53	11	40-66	21
VA-RW	12	58	11	41-70	19
VA-RW	5	48	13	37-69	27
VA-RW	6	77	7	64-84	9
VA-RW	8	74	4	66-78	5
VA-RW	4	75	10	61-84	13
VA-RW	4	71	3	68-75	4
VA-RW	25	67	7	52-80	10

TABLE 3. SUMMARY OF PCI FEATURE DATA FOR CONCRETE-SURFACED PAVEMENT (CONTINUED)

Feature	No. Samples	Mean PCI	Std. Dev.	Range	COV
VA-RW	10	72	16	41-97	22
HL-A	14	65	14	41-85	22
HL-A	17	76	14	44-94	18
HL-A	6	95	3	89-97	3
VA-A (24A)	5	61	13	40-69	21
VA-A (24B)	45	75	9	56-92	17
VA-A (24C)	10	71	12	50-92	17
VA-A (24D)	4	58	9	49-70	16
VA-A (25A)	15	55	14	28-80	25
VA-A (25B)	18	63	12	46-83	19
VA-A (25C)	6	65	15	46-86	23
VA-A (26)	6	86	2	81-88	2
VA-A (27)	10	71	11	39-76	15
VA-TW (3AB)	17	82	13	53-98	16
VA-TW (T5B)	11	78	10	63-98	13
VA-TW (T11B)	8	95	2	92-98	2
SH-TW (TIC)	4	45	15	24-60	33
SH-TW	3	36	19	17-55	53
SH-TW	10	80	14	57-98	17
SH-TW	10	61	24	13-92	39
SH-TW	8	57	14	28-81	25

TABLE 3. SUMMARY OF PCI FEATURE DATA FOR CONCRETE-SURFACED PAVEMENT (CONCLUDED)

Feature	No. Samples	Mean PCI	Std. Dev.	Range	COV
SH-RW	13	70	13	41-80	19
SH-AP	19 (all)	54	16	16-74	30

TABLE 4. SUMMARY OF PCI FEATURE DATA FOR ASPHALT-SURFACED PAVEMENT

Feature	No. Samples	Mean PCI	Std. Dev.	Range	COV	
SCOTT-TW	22	88	9	68-96	10	
Home-TW	5	52	13	42-73	25	
Geor.-TW	11	35	10	25-53	29	
Elm-RW	7	77	4	71-82	5	
Eie-RW	9	63	7	48-71	11	
McG-RW	20	20	7	10-35	35	
McG-RW	4	61	5	53-64	8	outside
McG-RW	23	45	8	26-65	18	
McG-RW	4	88	6	80-93	7	outside
EL-RW	7	68	9	57-79	13	
EL-AP	7	77	6	70-86	8	
EL-AP	7	85	2	83-88	2	
EL-RW	7	84	6	71-90	7	
EL-RW	15	89	5	81-98	6	
EL-TW	12	27	13	16-53	48	
EL-TW	4	12	11	0-22	92	
EL-TW	8	65	9	49-74	14	
VA-RW	13	92	3	87-98	3	
VA-RW	17	73	7	63-84	10	
VA-TW	4	80	10	64-86	12	
VA-TW	8	58	19	29-88	33	

TABLE 4. SUMMARY OF PCI FEATURE DATA FOR ASPHALT-SURFACED PAVEMENT (CONCLUDED)

Feature	No. Samples	Mean PCI	Std. Dev.	Range	COV
VA-TW	13	80	16	48-95	20
VA-TW	4	81	2	78-83	2
VA-RW	3	71	10	61-80	14
VA-TW (T15B)	11	83	10	65-91	12
HL-RW	27	87	6	73-94	7
HL-TW	12	69	7	58-83	10
HL-TW	10	48	18	7-68	37
HL-TW	9	49	8	40-59	16
HL-TW	12	63	9	49-76	14
SH-RW	10	77	10	50-84	13
SH-RW	6	90	5	81-93	6
SH-RW (R5C)	8	68	7	59-76	10

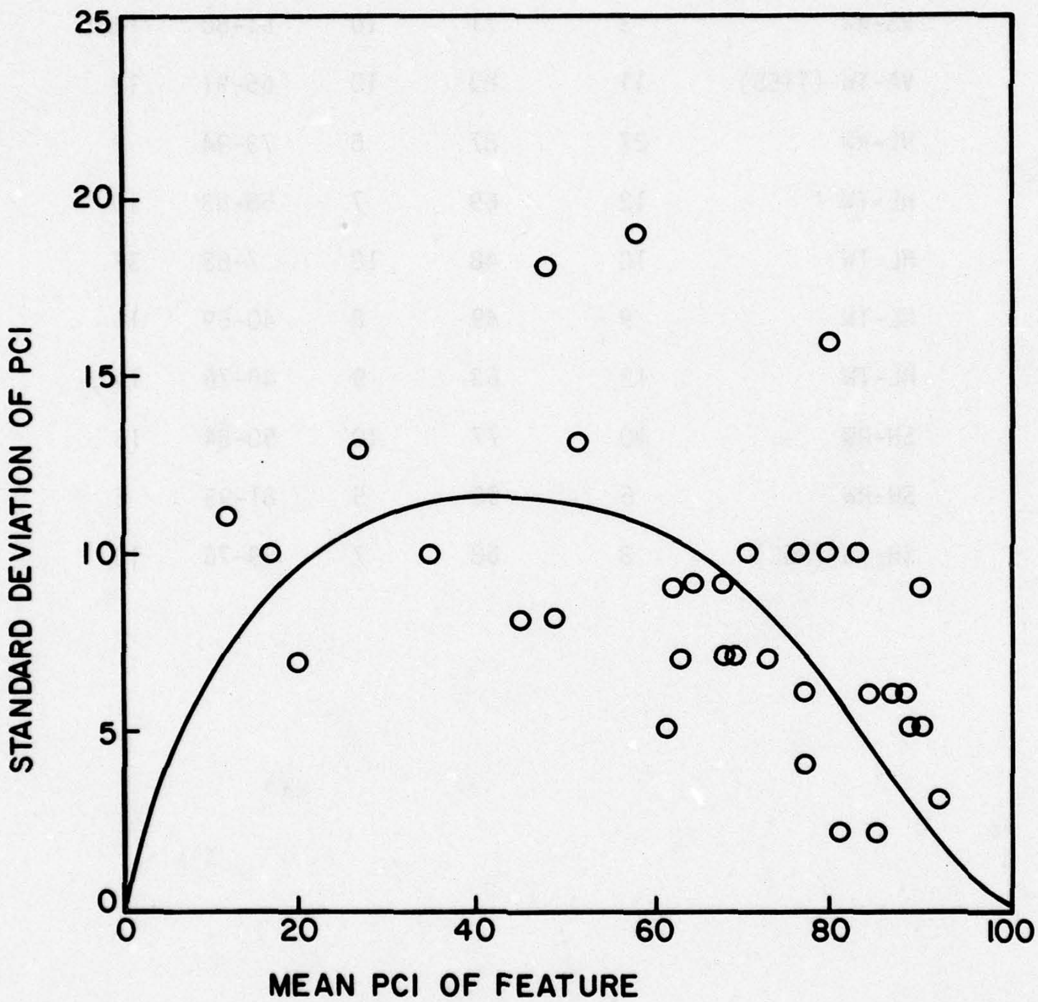


Figure 14. Mean PCI of Feature Versus Standard Deviation Within Feature for Asphalt-Surfaced Pavements (Each point represents one feature)

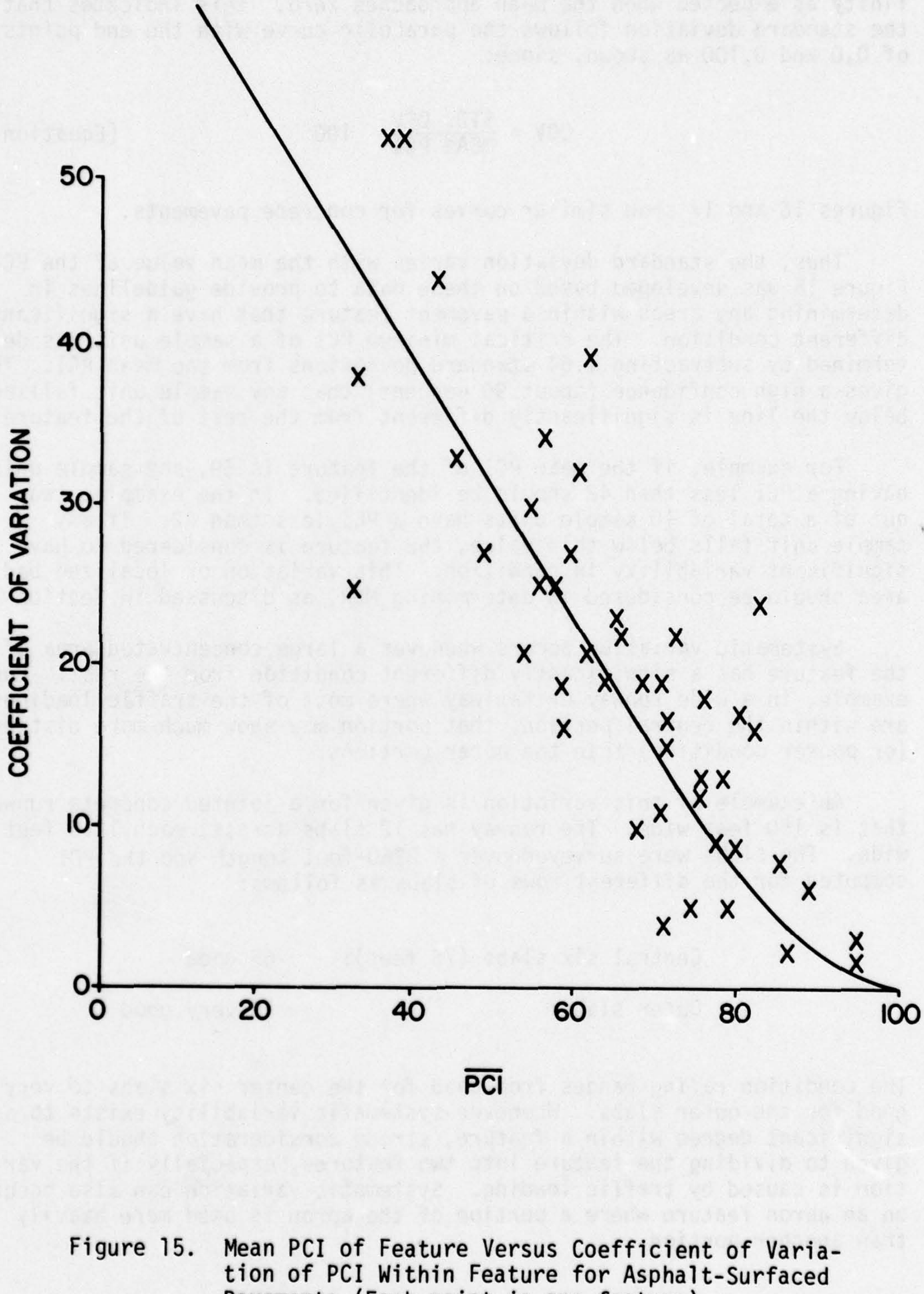


Figure 15. Mean PCI of Feature Versus Coefficient of Variation of PCI Within Feature for Asphalt-Surfaced Pavements (Each point is one feature)

the coefficient of variation (COV) and mean PCI, showing that as PCI decreases, the coefficient of variation increases, approaching infinity as expected when the mean approaches zero. This indicates that the standard deviation follows the parabolic curve with the end points of 0,0 and 0,100 as shown, since:

$$COV = \frac{\text{STD. DEV.}}{\text{MEAN PCI}} \; 100 \qquad \text{[Equation 3]}$$

Figures 16 and 17 show similar curves for concrete pavements.

Thus, the standard deviation varies with the mean value of the PCI. Figure 18 was developed based on these data to provide guidelines in determining any areas within a pavement feature that have a significantly different condition. The critical minimum PCI of a sample unit was determined by subtracting 1.64 standard deviations from the mean PCI. This gives a high confidence (about 90 percent) that any sample unit falling below the line is significantly different from the rest of the feature.

For example, if the mean PCI of the feature is 59, any sample unit having a PCI less than 42 should be identified. In the example, two out of a total of 10 sample units have a PCI less than 42. If any sample unit falls below this value, the feature is considered to have significant variability in condition. This variation or localized bad area should be considered in determining M&R, as discussed in Section V.

Systematic variation occurs whenever a large concentrated area of the feature has a significantly different condition from the rest. For example, in a wide runway or taxiway where most of the traffic loadings are within the central portion, that portion may show much more distress (or poorer condition) than the outer portions.

An example of this variation is given for a jointed concrete runway that is 150 feet wide. The runway has 12 slabs across, each 12.5 feet wide. The slabs were surveyed over a 2260-foot length and the PCI computed for the different rows of slabs as follows:

Central six slabs (75 feet):	65 good
Outer slabs:	79 very good

The condition rating ranges from good for the center six slabs to very good for the outer slabs. Whenever systematic variability exists to a significant degree within a feature, strong consideration should be given to dividing the feature into two features, especially if the variation is caused by traffic loading. Systematic variation can also occur on an apron feature where a portion of the apron is used more heavily than another portion.

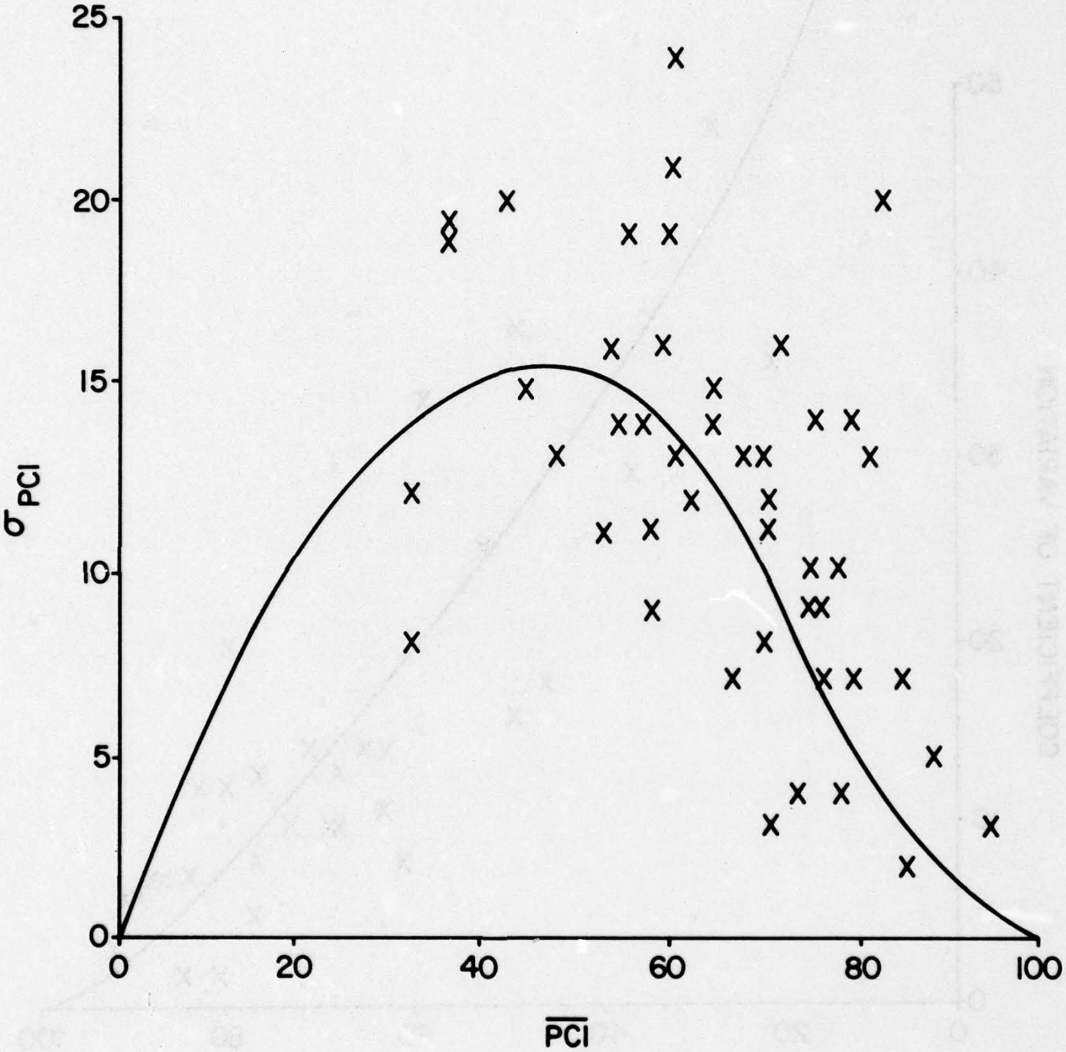


Figure 16. Mean PCI of Feature Versus Standard Deviation of PCI Within Feature for Concrete-Surfaced Pavement

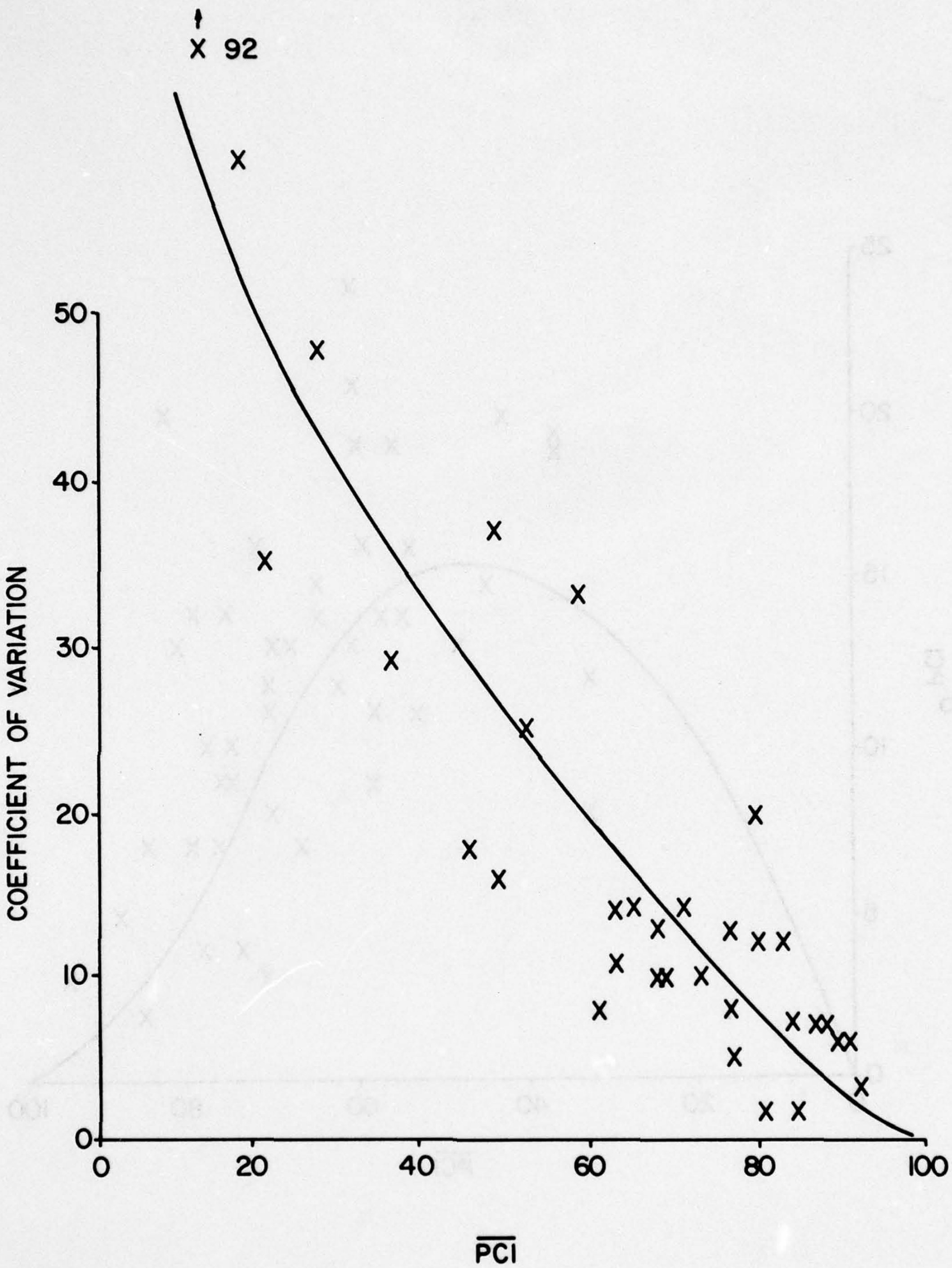


Figure 17. Mean PCI of Feature Versus Coefficient of Variation of PCI Within Feature for Concrete-Surfaced Pavements

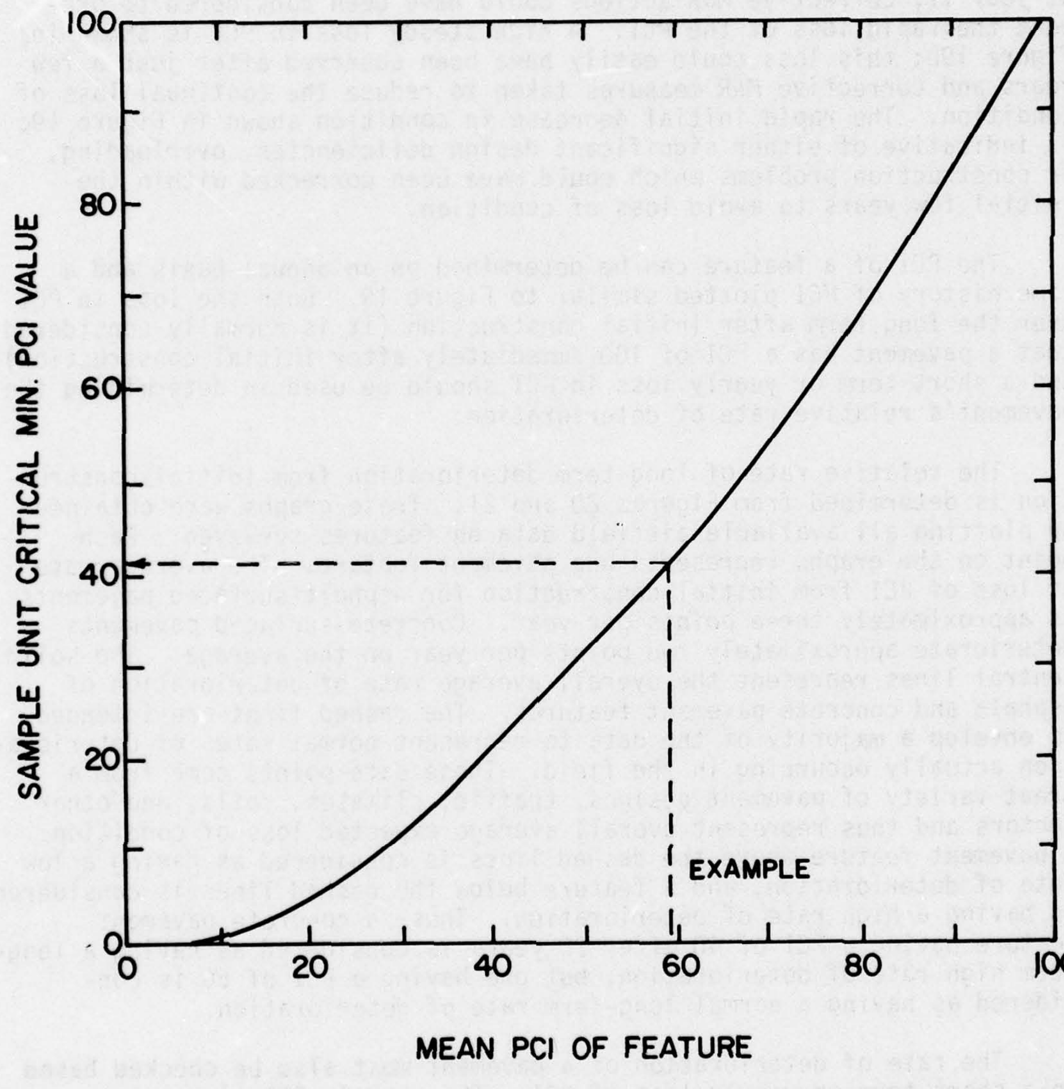


Figure 18. Procedure to Determine Minimum Sample Unit PCI Based on Mean PCI of Feature

RATE OF DETERIORATION

The rate of deterioration of a pavement feature under existing climate and traffic loadings is a very important factor. One of the most valuable indicators of condition is a time history plot of the mean PCI of the feature (or performance). Figure 19 shows examples of various performance curves for a feature. Figure 19a shows a very rapid rate of deterioration after 15 years. If this trend had been observed at year 17, corrective M&R actions could have been considered to prevent the rapid loss of the PCI. A high steady loss in PCI is shown in Figure 19b; this loss could easily have been observed after just a few years and corrective M&R measures taken to reduce the continual loss of condition. The rapid initial decrease in condition shown in Figure 19c is indicative of either significant design deficiencies, overloading, or construction problems which could have been corrected within the initial few years to avoid loss of condition.

The PCI of a feature can be determined on an annual basis and a time history of PCI plotted similar to Figure 19. Both the loss in PCI over the long term after initial construction (it is normally considered that a pavement has a PCI of 100 immediately after initial construction) and a short term or yearly loss in PCI should be used in determining the pavement's relative rate of deterioration.

The relative rate of long-term deterioration from initial construction is determined from Figures 20 and 21. These graphs were obtained by plotting all available airfield data on features surveyed. Each point on the graphs represents one pavement feature. The average rate of loss of PCI from initial construction for asphalt-surfaced pavements is approximately three points per year. Concrete-surfaced pavements deteriorate approximately two points per year on the average. The solid central lines represent the overall average rate of deterioration of asphalt and concrete pavement features. The dashed lines are intended to envelop a majority of the data to represent normal rates of deterioration actually occurring in the field. These data points come from a great variety of pavement designs, traffic, climates, soils, and other factors and thus represent overall average expected loss of condition. A pavement feature above the dashed lines is considered as having a low rate of deterioration, and a feature below the dashed lines is considered as having a high rate of deterioration. Thus, a concrete pavement feature having a PCI of 40 after 20 years is considered as having a long-term high rate of deterioration, but one having a PCI of 60 is considered as having a normal long-term rate of deterioration.

The rate of deterioration of a pavement must also be checked based on a short term or yearly loss of PCI. The example PCI-time curve shown in Figure 19 shows that this is an important consideration in determining any rapid loss in condition. Whenever the mean PCI of a feature decreases by seven or more PCI points, the rate of deterioration should be considered as high. The relative rate of deterioration for a pavement feature having a PCI of 80 in 1976 and 65 in 1977 is high according to this criterion. If the loss in PCI had been five points, the short-term rate of deterioration would be considered normal or average.

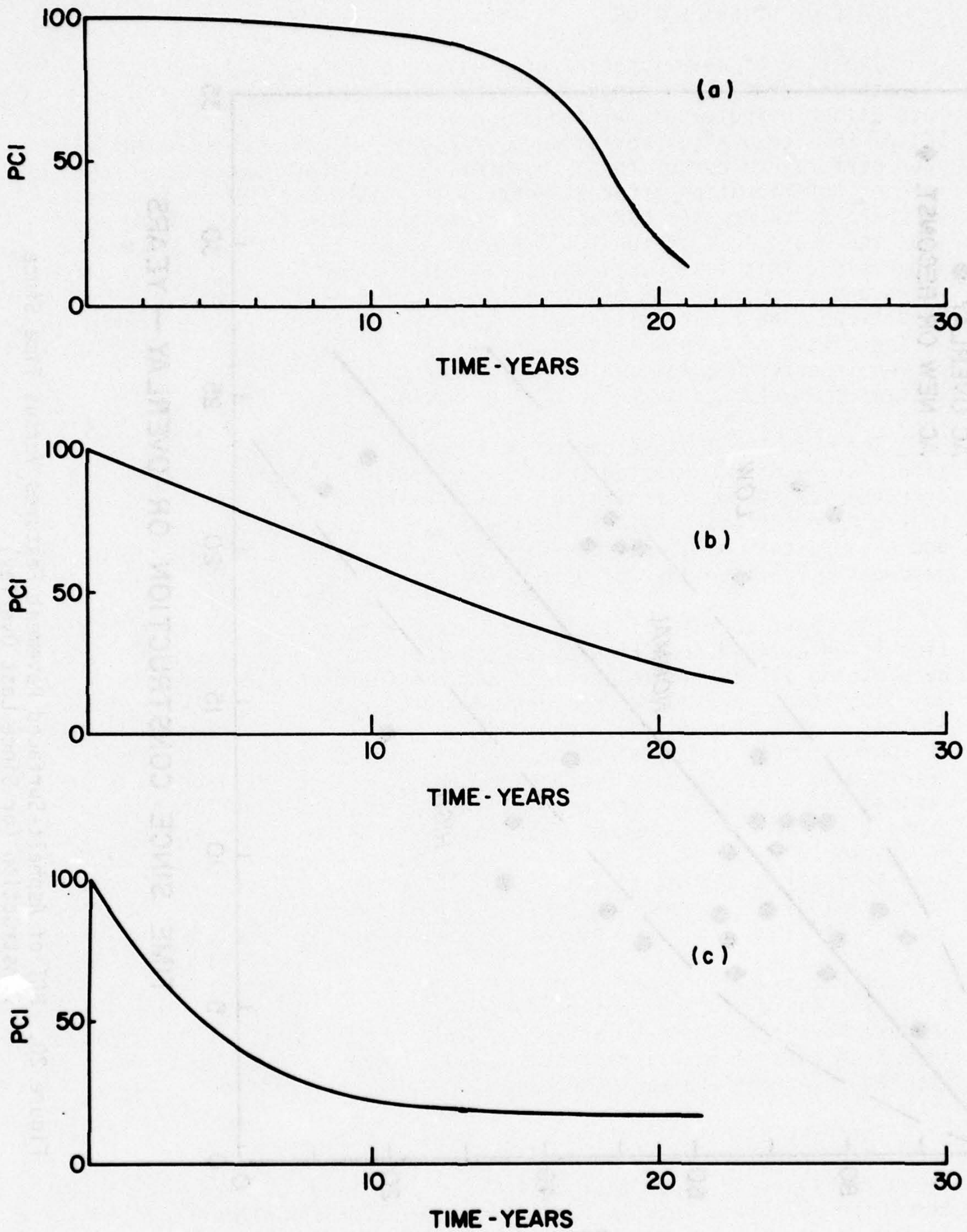


Figure 19. Illustration of Various Rates of Deterioration of Pavement Condition

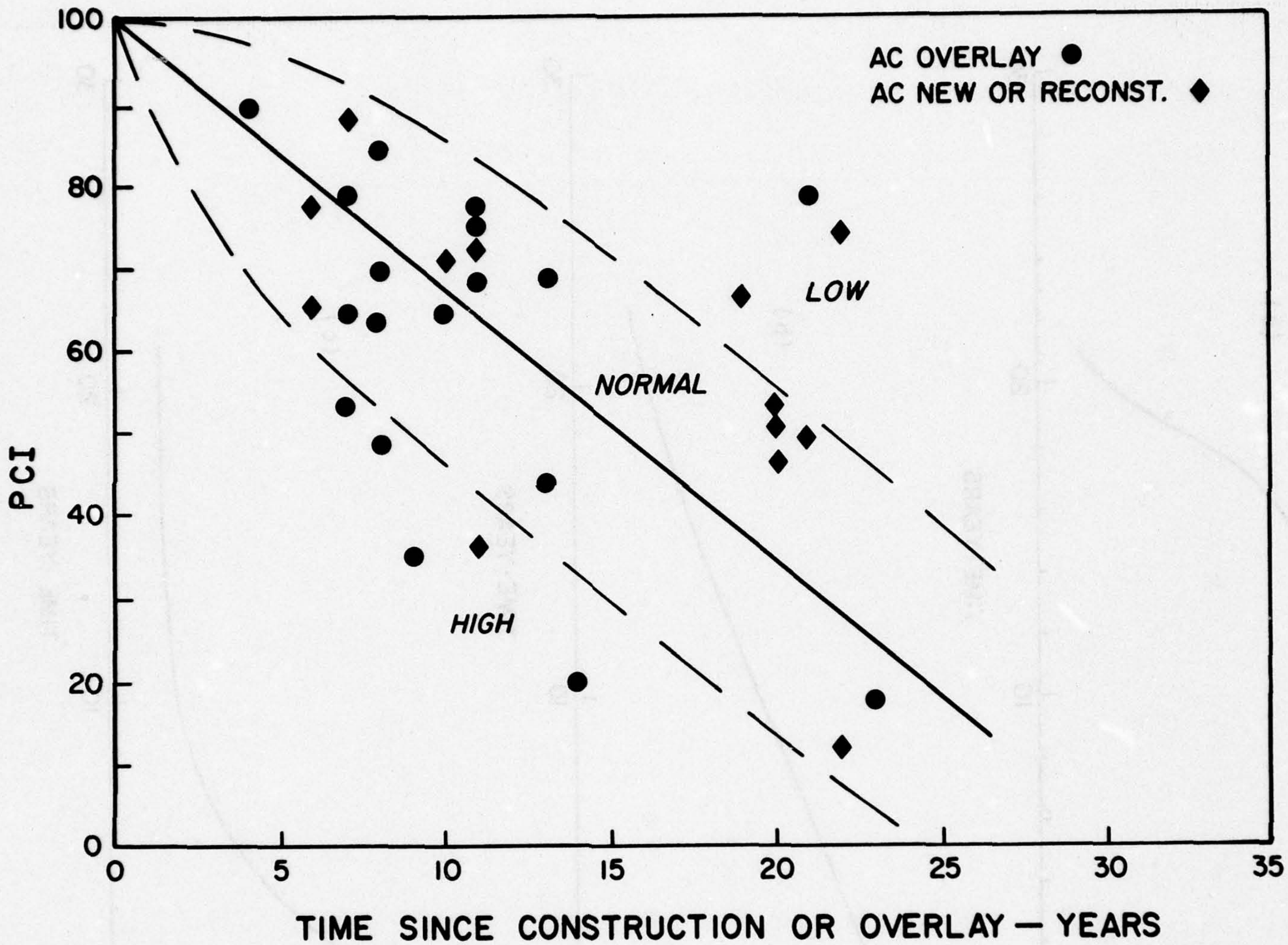


Figure 20. PCI of Asphalt-Surfaced Pavement Features Versus Time Since Construction (or Since Last Overlay)

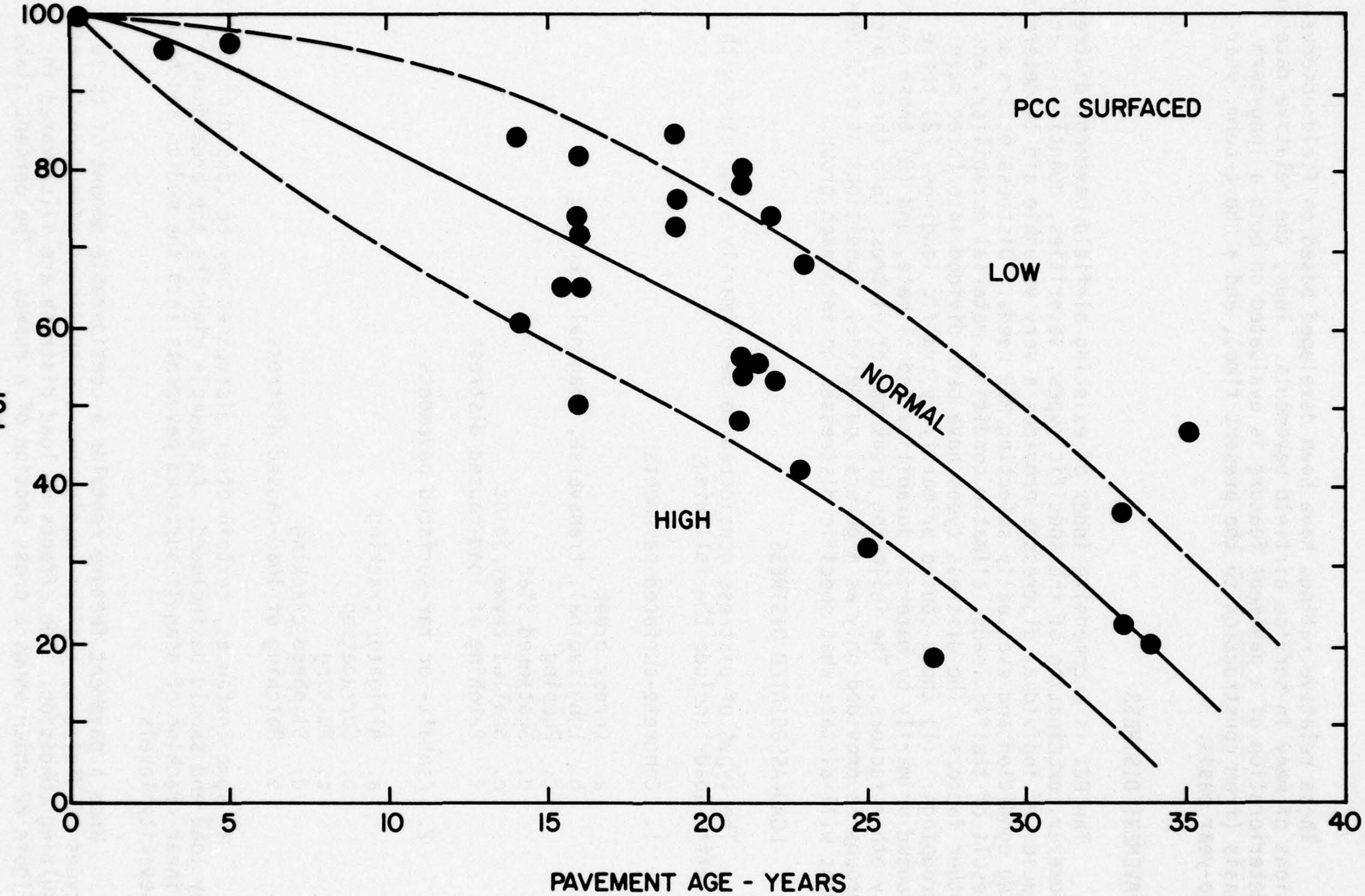


Figure 21. PCI of Concrete-Surfaced Pavement Features Versus Time Since Construction

These relative ratings have been developed based on field observations of many in-service airfield pavements. Thus, the relative rate of deterioration of a pavement feature is evaluated on both a long-term basis (from construction to the present time), and a short-term, year-to-year basis.

PAVEMENT DISTRESS

The PCI is a composite index of existing airfield pavement distress. However, examination of the specific types, severities, quantities, and causes of individual distresses provides a very valuable aid in determining condition and eventually selecting M&R needs. Distress occurs as a result of traffic loads, climatic condition, material durability, and other factors. The distress types have been divided into three main groupings: (1) those caused primarily by traffic loadings, (2) those caused primarily by material durability and climate, and (3) those caused by other factors. The following breakdown of distress into three main groups is provided only as a general guideline. Conditions at each pavement will dictate what specific distresses go into each group.

LOAD-ASSOCIATED DISTRESS

The types of distress considered to be primarily associated with traffic loads include the following:

1. Concrete-surfaced pavements

    a. Corner break
    b. Longitudinal, transverse, diagonal cracking
    c. Pumping
    d. Shattered Slab
    e. Spalled keyway joint
    f. Patching of load-caused distress

2. Asphalt- or tar-surfaced pavements

    a. Alligator cracking
    b. Corrugation
    c. Rutting
    d. Slippage cracking
    e. Patching of load-caused distress.

In some instances, certain other distresses may be caused primarily by load and should be included. An example might be the breakdown of linear cracking of asphalt-surfaced pavements into the medium and high severity levels.

When a pavement feature contains a considerable amount of these types of distress, traffic loading has a significant effect on the resulting condition. The effects of load distress are illustrated in Figure 22 which shows a cross section of a runway. The percent slabs

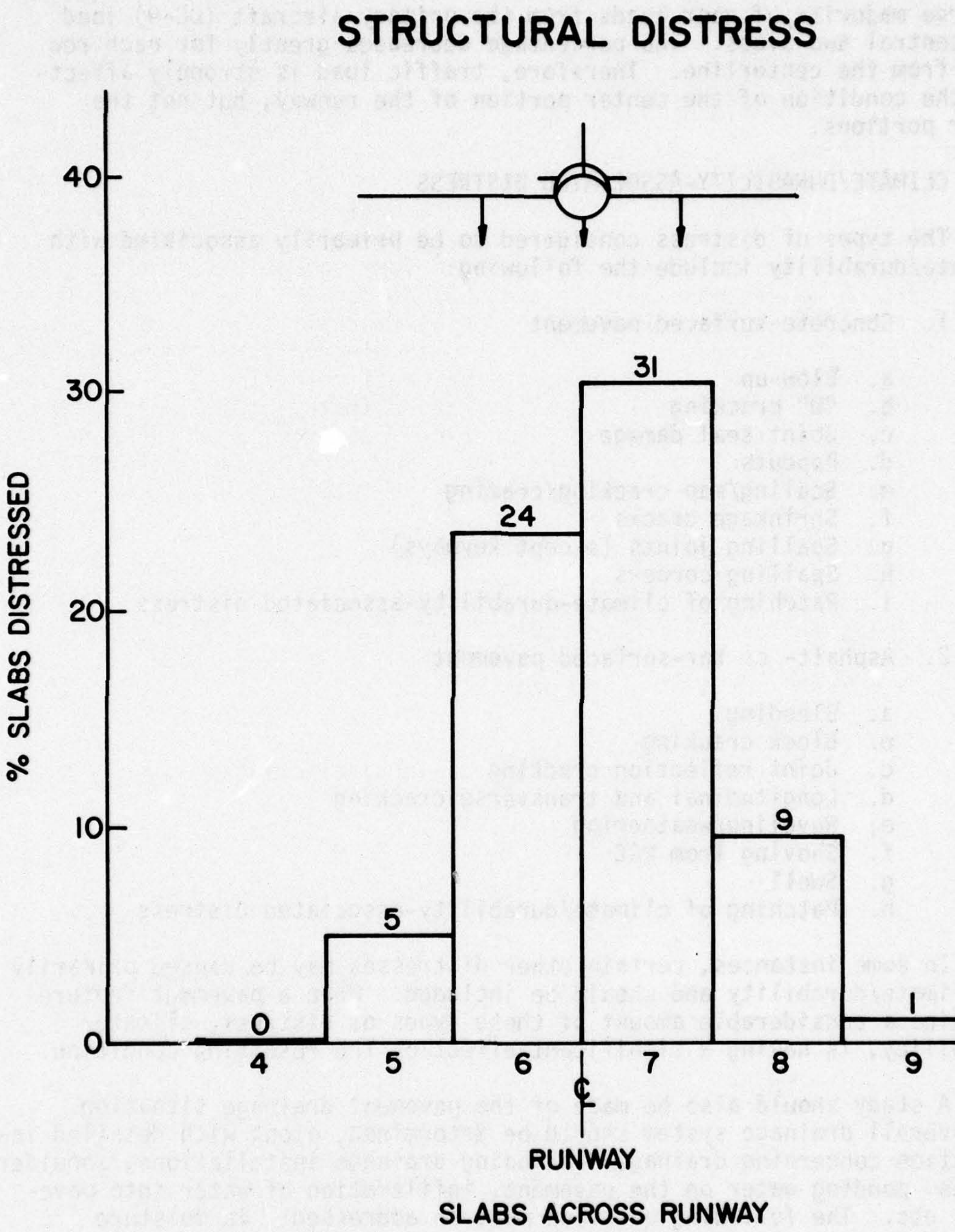


Figure 22. Effects of Load on Structural Distress on Runway

containing load-associated distress is much higher for the central two slabs (rows 3 and 4) than for the outer slabs (slabs 1 and 6), because a large majority of gear loads from the primary aircraft (DC-9) load the central two slabs. The percentage decreases greatly for each row away from the centerline. Therefore, traffic load is strongly affecting the condition of the center portion of the runway, but not the outer portions.

CLIMATE/DURABILITY-ASSOCIATED DISTRESS

The types of distress considered to be primarily associated with climate/durability include the following:

1. Concrete-surfaced pavement

   a. Blow-up
   b. "D" cracking
   c. Joint seal damage
   d. Popouts
   e. Scaling/map cracking/crazing
   f. Shrinkage cracks
   g. Spalling joints (except keyways)
   h. Spalling corners
   i. Patching of climate-durability-associated distress

2. Asphalt- or tar-surfaced pavement

   a. Bleeding
   b. Block cracking
   c. Joint reflection cracking
   d. Longitudinal and transverse cracking
   e. Raveling/weathering
   f. Shoving from PCC
   g. Swell
   h. Patching of climate/durability-associated distress

In some instances, certain other distresses may be caused primarily by climate/durability and should be included. When a pavement feature contains a considerable amount of these types of distress, climate/durability, is having a significant effect on the resulting condition.

A study should also be made of the pavement drainage situation. The overall drainage system should be determined, along with detailed information concerning drainage, including drainage installations, shoulder slopes, ponding water on the pavement, infiltration of water into pavement, etc. The following question must be addressed: is moisture causing accelerated deterioration of pavement condition? If so, how is moisture contributing (groundwater table, perched water tables, springs, infiltration of surface water, etc.)? If moisture is contributing significantly to the rate of deterioration of pavement condition, then ways must be sought to prevent or minimize this occurrence, as discussed in Section V. This factor should be evaluated subjectively by the engineer and rated as follows:

1. Minor - moisture is having only a very small effect, if any, on the deterioration of the pavement.

2. Moderate - moisture is having a significant effect on causing or accelerating the deterioration of the pavement.

3. Major - moisture is having a very strong effect on causing or accelerating the deterioration of the pavement.

OTHER ASSOCIATED DISTRESS

The types of distress considered to be primarily associated or caused by factors other than load and climate/durability are as follows:

1. Concrete-surfaced pavement

   a. Settlement/fault
   b. Patching of other distress

2. Asphalt- or tar-surfaced pavement

   a. Depression
   b. Jet blast
   c. Oil spillage
   d. Polished aggregate
   e. Patching of other distress

When a pavement feature contains a considerable amount of any of these types of distress, each distress is evaluated separately, since each distress is generally caused by a different factor. If two or more of these distresses are caused by the same factor, they should be combined and considered together.

EVALUATION OF DISTRESS

The following steps comprise a procedure for determining the primary cause or causes of the deterioration of pavement condition for a given feature:

1. The total deduct values attributable to load, climate/durability, and other associated distress are separately determined. For example, the following distresses were measured on a feature and the deduct values determined:

Distress Type	Deduct Value	Cause
Alligator Cracking	50	Load
Transverse Cracking	8	Climate/Durability
Rutting	20	Load

The total deduct value attributable to load is 70; that attributable to climate/durability is 8.

2. The percentage deducts attributable to load, climate/durability, and other causes are computed. For the above example feature, the calculation is as follows:

Load = 70/78 x 100	=	90 percent
Climate/Durability = 8/78 x 100 =		10 percent
Total	=	100 percent

3. The percent deduct values attributed to each cause forms the basis for determination of the primary cause(s) of pavement deterioration. In this example, distresses caused primarily by load have resulted in 90 percent of the total deducts, whereas all other causes amount to only 10 percent. Thus, traffic load is by far the major cause of deterioration of this pavement feature.

LOAD CARRYING CAPACITY EVALUATION

The load carrying capacity of an airfield pavement is defined in terms of three factors: (1) the aircraft gross weight, (2) aircraft type, and (3) number of aircraft passes over the pavement until a "failed" condition is predicted. If these three factors are held constant, the load carrying capacity depends on the pavement structure and material properties and subgrade soil properties. For years, the Air Force has determined the load carrying capacity of airfield pavements using procedures developed by the Corps of Engineers.[3] The procedures are based on actual field results from several full-scale test pavement programs.

Typical determination of the load carrying capacity of a pavement feature for a given aircraft requires determination of the maximum allowable gross weight of the aircraft for the six operational categories defined in Table 5. Detailed procedures which may be used for determining the load carrying capacity are provided in Chapters 2 and 3 of AFM 88-24.

However, for convenient use, a series of pavement evaluation curves developed by the Waterways Experiment Station (WES) for the Air Force may be used. These curves, which have been developed for both flexible (asphalt) and rigid (concrete) pavements for most aircraft types, are currently being incorporated into a revised version of AFM 88-24. Figures 23 and 24 give sample curves for DC-9 aircraft for rigid and flexible pavements. The following information is needed to use the concrete evaluation curves (example data are provided):

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[3] Airfield Pavement, AFM 88-24, Chapter 2, "Flexible Airfield Pavement Evaluation," and Chapter 3, "Rigid Airfield Pavement Evaluation" (Department of the Air Force, 1965).

TABLE 5. DEFINITIONS OF OPERATIONAL CATEGORIES USED IN LOAD CARRYING CAPACITY EVALUATION[a]

1. Capacity. Maximum allowable loadings for unlimited aircraft operations for a period of more than 10 years.

2. Full. Maximum allowable loadings for normal aircraft operations for a period of 1 to 2 years.

3. Minimum. Maximum allowable loadings for normal aircraft operations for a period of 4 to 6 months.

4. Emergency. Maximum allowable loadings for normal aircraft operations for a period of 2 to 3 weeks.

5. Frost Capacity. Maximum allowable loadings for unlimited operations during the period of weakening due to frost for a period of more than 10 years.

6. Frost Limited. Maximum allowable loadings for approximately one-tenth of the normal number of aircraft operations during the period of weakening due to frost.

[a]From AFR 93-5, Chapter 2.

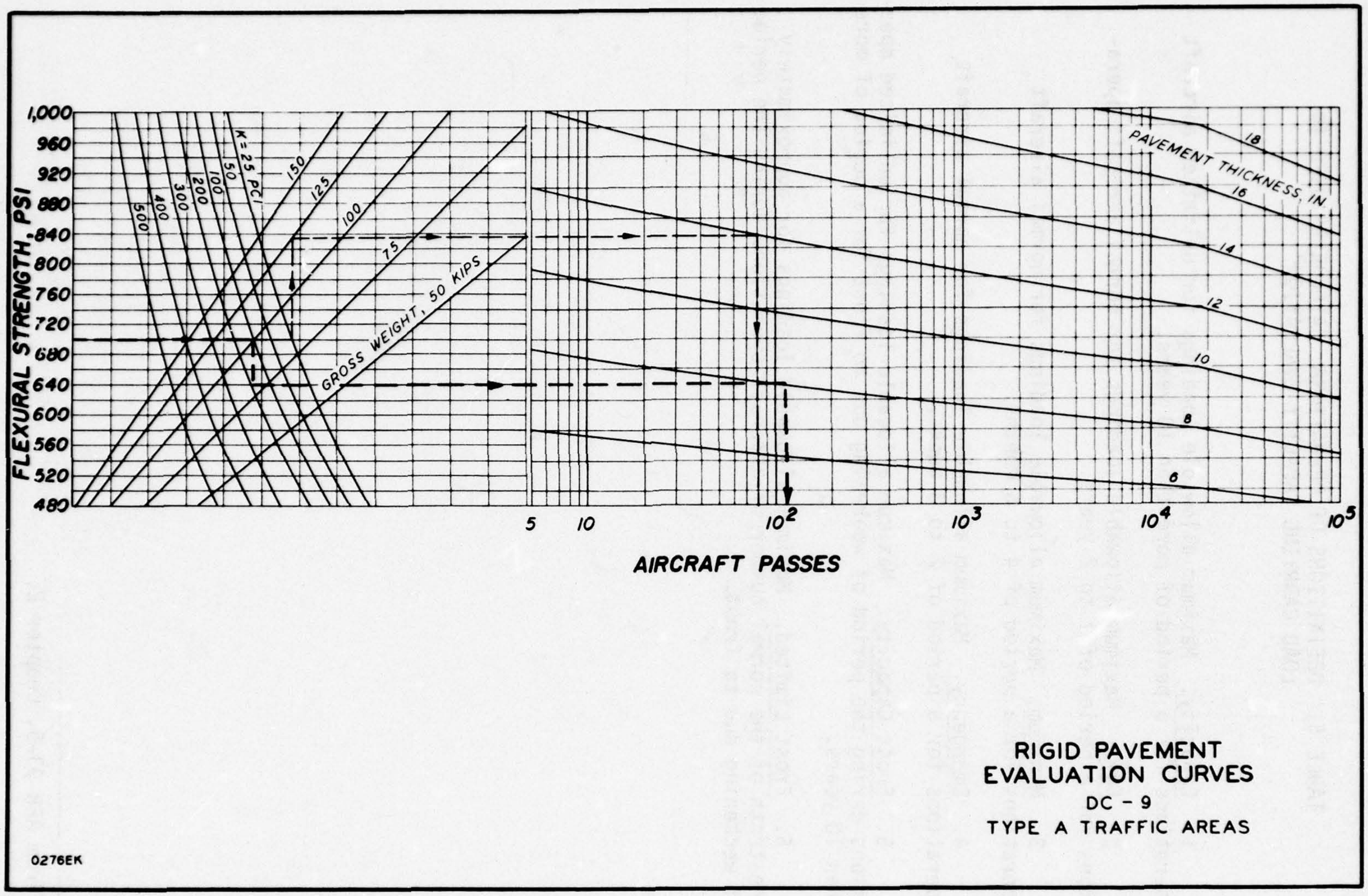

Figure 23. Rigid Pavement Evaluation Curves, DC-9, Type A Traffic Areas

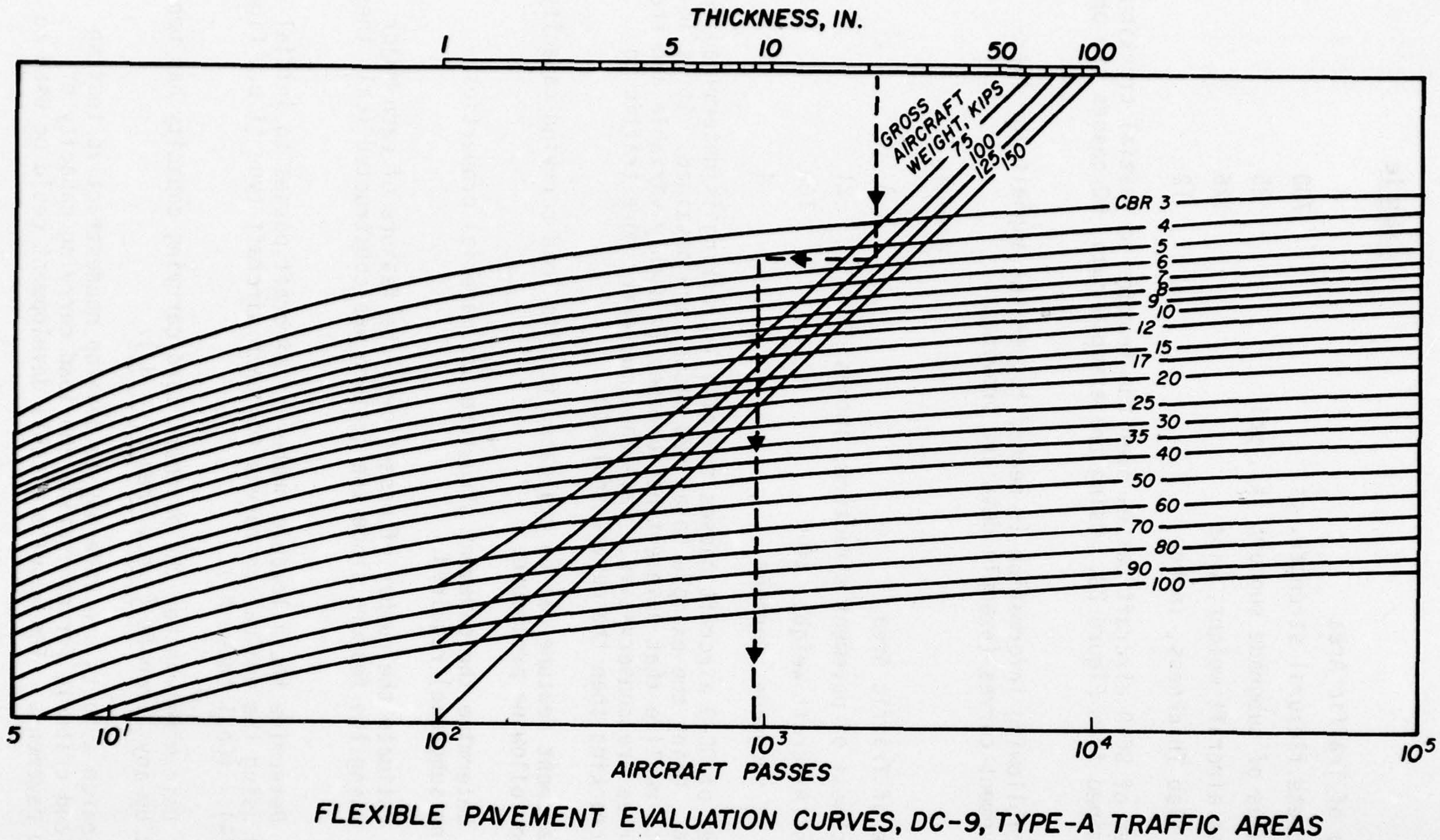

Figure 24. Flexible Pavement Evaluation Curves, DC-9, Type A Traffic Areas

	Example
Type of Traffic Area	A
Concrete flexural strength, psi	700
Modulus of subgrade support (k), pci	25
Gross aircraft weight, kips	125
PCC Slab Thickness, inches	12

The number of DC-9 aircraft passes over the feature to initial cracking is determined from Figure 23. Using the example data, 80 passes are obtained.

The following information is needed to use the asphalt (or flexible) pavement curves (example data are provided):

	Example
Type of Traffic Area	A
Thickness of pavement structure, inches	21
Gross Aircraft Weight, kips	100
CBR of Subgrade, percent	4

The number of DC-9 aircraft passes to initial cracking is determined from Figure 24. Using the example data, 920 passes are obtained. *It is important* to realize that pavement performance is highly variable and that these curves are conservative. Pavements may carry more traffic to initial cracking than the curves indicate.

A pavement feature can be evaluated for its load carrying capacity using the following procedure:

1. Determine the pavement structure and material properties (including subgrade) required.

2. Estimate the number of passes over the feature of each major aircraft using the feature since the feature was constructed (call these n_i).

3. Determine the allowable number of aircraft passes to initial cracking using the evaluation curves for each aircraft type (i.e., Figures 23 and 24). (Call these N_i).

4. Determine whether the pavement load carrying capacity has been exceeded by any aircraft (i.e., when $n_i > N_i$).

Research efforts are underway to develop nondestructive testing methods and criteria for evaluating the load carrying capacity of airfield pavements. The results of this development could be used to

replace the procedure outlined herein. Since the new procedure would be based on direct measurement of the pavement feature under consideration, its results would be expected to be better than those of the current methods.

SURFACE ROUGHNESS

In 1972, the Federal Aviation Administration (FAA) and Air Force initiated a joint program to measure surface roughness and analyze its effects on aircraft ride quality. It was recognized initially that roughness was most likely independent of observable pavement distress to some degree. In one case (Washington National), pilot complaints of alarming aircraft shock and vibration levels were largely responsible for resurfacing the pavement. After resurfacing, with presumably no observable pavement distress, pilot complaints were even stronger.

There are presently three methods of estimating surface roughness. First, pilot complaints are considered to be subjective but highly reliable sources of qualitative roughness information. The pilot reports reflect aircraft ride quality as well as surface roughness; the additional factor of aircraft vibration is therefore included.

Second, certain factors which contribute to the PCI may be correlated with roughness to some extent. In asphalt pavements, pertinent distress types are corrugation, depression, raveling/weathering, rutting, shoving, and swelling. In concrete pavements the types are blowup, settlement or faulting, shattered slabs, cracking, and spalling. To a large extent, these PCI factors are also subjective for the purpose of estimating profile roughness. Experience has indicated that it is difficult or impossible to see the appropriate range of wavelengths which affect aircraft ride quality while inspecting a runway surface.

Third, the roughness may be quantitatively evaluated, on a relative basis, analyzing measured profile elevation data. The development of this approach formed a large part of the joint FAA and Air Force research program, and is discussed in more detail in Appendix F. This method required the development of rapid elevation measuring instruments and suitable data processing techniques involving filtering and statistical analysis of random data. The use of computer programming to estimate aircraft vibration response was also required.

Both PCI and surface elevation data were measured at Ellsworth and Vance AFBs on several features. The data were compared for evidence of dependence for indicators of surface roughness. A statistical regression and correlation analysis was used on these data to determine if PCI could be used to estimate roughness (or vice versa). Results of this study are given in Appendix F. In summary, some significant correlation was observed. The available data indicate that the lower the mean feature PCI, the higher the root mean square of elevation data. However, there has not been enough data analyzed to warrant a firm conclusion. It is presently conjectured that if the roughness is originally built into the pavement (as is probable for Ellsworth and the original

case of Washington National mentioned above), there will be no correlation. On the other hand, if the roughness results from pavement deterioration, there is reason to expect the appropriate PCI factors and the profile statistics to be correlated, since roughness considerations were made in the development of the PCI deduct value curves.

Thus, pavement surface roughness can be evaluated using the subjective rating of pilots, observation of pavement distress that usually causes roughness, and use of actual surface elevation data from the USAF evaluation equipment (if it can be obtained). The pavement roughness should be rated as minor, moderate, or major depending on these results:

1. Minor--existing pavement is causing little or no roughness to aircraft and few or no pilot complaints have been received.

2. Moderate--existing pavement is causing some roughness to aircraft and some pilot complaints have been received. There may be observable distress contributing to the roughness condition, or the roughness may be caused from construction defects.

3. Major--existing pavement is causing a significant amount of roughness to aircraft and many pilot complaints have been received. Observable distress that is contributing to the roughness probably exists, and/or the roughness may be caused by construction defects.

SKID RESISTANCE/HYDROPLANING POTENTIAL

The Air Force has developed and used a skid resistance/hydroplaning evaluation system on many airfield runways since about 1973. Ballentine[4] describes the standard skid resistance evaluation test in detail. The skid resistance/hydroplaning characteristics of the runway surface are evaluated from measurements obtained from two types of test equipment: the Mu-Meter and the diagonally braked vehicle (DBV). The evaluation consists of field measurements under dry and standardized artificially wet conditions. The pavement skid resistance data are reported in terms of the coefficient of friction (MU) determined from the Mu-Meter, and the wet-to-dry stopping distance ratio (SDR) measured by the diagonally braked vehicle. These vehicles are described by Shahin and Darter[5] and Williams.[6]

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[4] G. D. Ballentine, The Air Force Weapons Laboratory Skid Resistance Research Program, 1969-1974, Final Report AFWL-TR-74-181 (Air Force Weapons Laboratory, 1975).

[5] M. Y. Shahin and M. I. Darter, Pavement Functional Condition Indicators, Technical Report C-15/ADA007152 (U.S. Army Construction Engineering Research Laboratory [CERL], 1975).

[6] J. H. Williams, Analysis of the Standard USAF Runway Skid Resistance Tests, Final Report AFCEC-TR-75-3 (AFCEC, 1975).

Research data were used to develop breakpoints in the values of MU and SDR which define potential hydroplaning problems. The evaluation ratings are summarized in Tables 6 and 7. Transverse slope measurements are also made along both sides of the runway centerline; these measurements indicate the drainage characteristics of the runway surface. Slopes downward from the centerline indicate that water drains to the runway edge, whereas an upward slope indicates the drainage crosses the runway centerline before draining to the edge. Recommended guidelines show that surface slopes in excess of 1 percent promote good to excellent drainage conditions. The drainage characteristics of the runway are rated in terms of this general statement.[7]

Thus, measurements are required to adequately evaluate the skid resistance/hydroplaning characteristics of a runway. Periodic evaluation at about 5-year intervals is the current Air Force procedure. If the equipment is not available, the engineer can make an approximate evaluation based on visual observations. Distress types on asphalt- and concrete-surfaced pavements that cause skid resistance/hydroplaning problems are shown in Figures 11 and 12. Measurement of the transverse slope can also be accomplished through standardized survey techniques.

PREVIOUS M&R APPLIED

A pavement feature can be kept in operating condition almost indefinitely if extensive M&R is continually applied. There are major drawbacks to this maintenance strategy, however, such as overall cost, downtime of feature, limitations of manpower and equipment and airfield mission requirements. The amount and type of previous M&R applied to a pavement feature are important factors in deciding currently needed M&R. A pavement feature may have a fairly high PCI and a moderate amount of distress at the time of the evaluation survey, but if a large portion has been patched or replaced, the PCI would not give a true indication of overall pavement condition. A pavement in this condition must have had many previous distress problems which are likely to continue in the future.

The following procedure can be used to determine the relative amount of previous M&R:

1. Summarize all M&R applied to the feature since construction in terms of type and amount. Some of this information can be directly determined from a visual survey of the feature.

2. Determine whether the feature has had low, normal (or average), or high amounts of previous M&R using the following guidelines:

a. Compute the percent area patched for asphalt-surfaced pavements (include all types of patching). Compute the percent area

[7] G.D. Ballentine, The Air Force Weapons Laboratory Skid Resistance Research Program, 1969-1974, Final Report AFWL-TR-74-181 (Air Force Weapons Laboratory, 1975).

TABLE 6. MU-METER AIRFIELD PAVEMENT RATING[a]

MU	Expected Aircraft Braking Response	Response
Greater than 0.50	Good	No hydroplaning problems are expected
0.42 - 0.50	Fair	Transitional
0.25 - 0.41	Marginal	Potential for hydroplaning for some aircraft exists under certain wet conditions
Less than 0.25	Unacceptable	Very high probability for most aircraft to hydroplane

[a]From G. D. Ballentine, The Air Force Weapons Laboratory Skid Resistance Research Program, 1969-1974, Final Report AFWL-TR-74-181 (Air Force Weapons Laboratory, 1975).

TABLE 7. STOPPING DISTANCE RATIO AIRFIELD PAVEMENT RATING (DIAGONALLY BRAKED VEHICEL)[a]

SDR	Hydroplaning Potential
1.0 - 2.5	No hydroplaning anticipated
2.5 - 3.2	Potential not well defined
3.2 - 4.4	Potential for hydroplaning
Greater than 4.4	Very high hydroplaning potential

[a]From G. D. Ballentine, The Air Force Weapons Laboratory Skid Resistance Research Program, 1969-1974, Final Report AFWL-TR-74-181 (Air Force Weapons Laboratory, 1975)(Source of Ratings Adjusted to Reflect Use of 15 Inch Tires on the Diagonally Braked Vehicle. Values shown are subject to further revision).

patched for concrete-surfaced pavements (include only large patches of more than 5 square feet and slab replacements). Determine the evaluation rating according to Figure 25.

b. Some pavements may have received an excessive amount of other types of M&R (other than patching considered in a). If in the judgment of the engineer this feature should be evaluated as high previous maintenance, then this evaluation should take precedence over the evaluation determined in Figure 25 based on only patching and slab replacement.

The evaluation rating procedure shown in Figure 25 is based on expenditure of maintenance funds. The high rating essentially means that an unusually large amount of funds has been spent on M&R since construction of the feature, for example. The normal rating indicates that an average amount of M&R has been applied. The low indicates that less than average M&R has been applied.

EVALUATION SUMMARY

A pavement feature condition evaluation summary should be prepared based on the results obtained from the eight major condition indicators (Figure 26). Procedures have been developed to determine the condition evaluation of each of these eight indicators and subindicators. In some cases where equipment is not available for direct measurement (i.e., skid resistance, roughness), the engineer can make an approximate evaluation as described.

The overall condition of the pavement feature can be summarized by completing the summary sheet shown in Figure 26. Certain of these indicators should correlate or relate to each other. These results can assist in determining appropriate M&R alternatives for the feature.

An example of a pavement condition evaluation is given in Section VII.

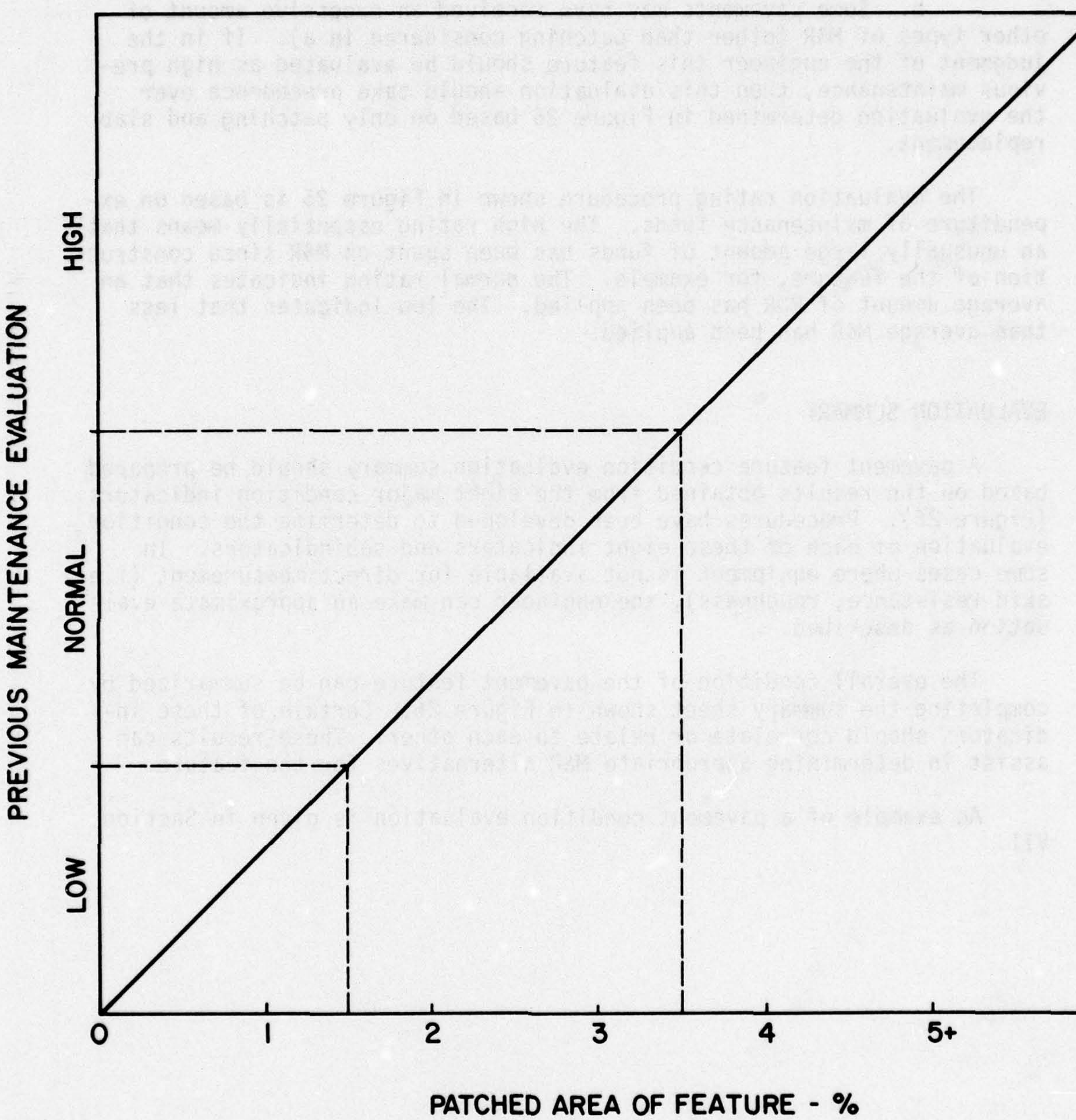

Figure 25. Evaluation Rating for Previous M&R Applied

1. Overall Condition Rating - PCI
Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

   a. Localized Random Variation — Yes, No
   b. Systematic Variation: — Yes, No

3. Rate of Deterioration of Condition - PCI

   a. Long-term period (since construction) — Low, Normal, High
   b. Short-term period (1 year) — Low, Normal, High

4. Distress Evaluation

   a. Cause

      Load Associated Distress — ___percent deduct values
      Climate/Durability Associated — ___percent deduct values
      Other (___) Associated Distress — ___percent deduct values

   b. Moisture Accelerated Distress — Minor, Moderate, Major

5. Load Carrying Capacity Deficiency — No, Yes

6. Surface Roughness — Minor, Moderate, Major

7. Skid Resistance/Hydroplaning (runways only)

   a. Mu-Meter
      - No hydroplaning problems are expected
      - Transitional
      - Potential for hydroplaning
      - Very high probability

   b. Stopping Distance Ratio
      - No hydroplaning anticipated
      - Potential not well defined
      - Potential for hydroplaning
      - Very high hydroplaning potential

   c. Transverse Slope — Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

Figure 26. Airfield Pavement Condition Evaluation Summary

SECTION V

GUIDELINES FOR DETERMINING M&R REQUIREMENTS

INTRODUCTION

This section presents guidelines for selecting feasible M&R alternative methods for airfield pavement features. The guidelines are based on results obtained from the condition evaluation and M&R zones established in this section. Section VIII of Volume I contained tentative guidelines for determining M&R requirements based on the PCI. Since Volume I was published, however, these guidelines have been evaluated, modified, and improved through extensive field surveys of airfield pavements and interviews with base and major command engineers. The M&R guidelines were then verified and finalized in a workshop attended by Air Force major command pavement engineers and other experienced pavement engineers from the Air National Guard Bureau, the Air Force Engineering School, and CERL.

M&R CATEGORIES

M&R methods such as crack filling, patching, slab replacement, and overlay can be grouped into three general categories for convenience of analysis and discussion:

1. Routine M&R. Routine M&R consists of performing preventive and/or localized M&R. Preventive M&R includes methods that preserve pavement condition and retard its deterioration. These methods include crack sealing, joint sealing, and application of fog seals and rejuvenators. Application of aggregate seal, however, is considered to be major localized M&R (see next category). Localized M&R methods are those that restore pavement condition. Some repair methods are considered localized if they are only applied to a small area of the pavement feature; for example, skin patching, applying heat and rolling sand, placing small patches (less than 5 square feet), and patching joint and corner spalls are considered localized regardless of amount. On the other hand, partial-depth or full-depth patching, slab replacement, slab undersealing, slab jacking, and slab grinding are considered localized only if applied to a small area of the pavement feature (usually less than 3.5 percent).

2. Major Localized M&R. Major localized M&R is an extensive form of localized M&R. It includes partial-depth or full-depth patching, slab replacement, slab undersealing, and slab grinding. These methods are considered major localized M&R only when applied to a considerable area or portion of the pavement feature (usually over 3.5 percent of the feature). Other M&R methods included under the major localized category are application of aggregate seal over the entire feature and the reconstruction of many joints in a concrete pavement.

3. Overall M&R. Overall M&R covers the entire pavement feature and usually improves its load carrying capacity. Overall M&R includes overlay with asphalt or concrete, reprocessing or recycling existing pavements, and total reconstruction. These are subsequently described in more detail.

ROUTINE AND MAJOR M&R METHODS FOR INDIVIDUAL DISTRESSES

Regardless of which M&R category is selected, individual distresses should be repaired, except when recycling or reconstruction is selected. Recommended methods for the repair of individual distresses were developed as a result of questionnaires sent to field engineers; the methods were then finalized in a workshop attended by 10 experienced pavement engineers. These recommendations are presented in Tables 8 and 9 for jointed concrete and asphalt- or tar-surfaced airfield pavements, respectively. The letters L, M, and H used in the tables indicate the distress level of severity (L = low, M = medium, and H = high).

Most of the listed repair methods are self-explanatory, with the exception of the different types of patching, which are defined below:

1. Full-depth patch. All pavement layers above the subgrade are removed and new material is placed.

2. Partial-depth patch. Only bad pavement material is removed (not all the way to the subgrade) and new material is placed.

3. Skin patch. No pavement material is removed. New material is placed on top of existing pavement surface and compacted.

It should be noted that for a given distress type and level of severity, more than one repair method may be recommended. For example, to repair a high-severity longitudinal/transverse/diagonal crack in a slab (distress No. 3, Table 8), any of the following repair methods may be used: crack sealing, partial-depth patch, full-depth patch, or slab replacement. The selection of one of these methods is left to the judgment of the pavement engineer based on existing field conditions. For example, if the high-severity cracked slab is caused by two cracks, one of which is low severity and the other medium, crack sealing is sufficient. However, if both cracks are severely spalled and pieces of the slab are acting independently, slab replacement may be necessary to restore the pavement structural integrity.

OVERALL M&R ALTERNATIVES

This section summarizes feasible overall M&R alternatives for jointed concrete and asphalt- or tar-surfaced airfield pavements.

TABLE 8. RECOMMENDED PREVENTIVE AND LOCALIZED M&R METHODS FOR JOINTED CONCRETE SURFACED AIRFIELD PAVEMENTS

DIST. TYPE \ M&R METHOD	DO NOTHING	CRACK SEALING	JOINT SEALING	PARTIAL DEPTH PATCH (BONDED)	FULL DEPTH PATCH	SLAB REPLACE-MENT	UNDER-SEAL	GRINDING SLAB	SLAB JACK-GROUT	NOTES
1 Blow-up				L*,M*	H*	H*				*Must provide expansion joint
2 Corner Break	L	L,M,H			M,H					
3 Long/Trans/ Diag. Crk	L	L,M,H		H*	H	H				*Allow Crack to Continue through patch except when using A.C.
4 "D" Crk	L	L*	L*	M,H	M,H	H				*If "D" Crk. exists, seal all joints and cracks.
5 Joint Seal Damage	L		M*,H							*Joint Seal Local Areas
6 Small Patch less than 5 ft.	L	M		M*, H*	H*					*Replace Patch
7 Large Patch greater than 5 ft.	L	M		M*,H*	H*	H				
8 Popouts	A									
9 Pumping		A	A				A			
10 Crazing/ Sealing	L			M,H		H*				*Only when surface is unacceptable
11 Settlement/ Faulting	L					H		M,H	M,H	
12 Divided Slab		L,M,H				M,H				
13 Shrinkage Crk	A									
14 Spalling Joint	L		L,M	L,M,H	M,H*	M,H*				*If caused by keyway failure provide Load transfer.
15 Spalling Corner	L		L,M	M,H						

A = distress type having only one severity level
L = distress at low severity
M = distress at medium severity
H = distress at high severity

TABLE 9. RECOMMENDED PREVENTIVE AND LOCALIZED M&R METHODS FOR ASPHALT- OR TAR-SURFACED AIRFIELD PAVEMENTS

Dist. Type	Do Nothing	Crack Seal	Partial Depth Patch	Full Depth Patch	Skin Patch	Apply Heat and Roll Sand	Fog # Seal (Emulsion)	Apply Rejuvenator	Apply Agg. Seal Coat	NOTES
1 Allig. Crk			M, H	M, H				L, M		
2 Bleeding	A					A				
3 Block Cr,	L	L, M, H						L	L, M	
4 Corrugation	L		M, H	M, H						
5 Depression	L		M, H	M, H	M, H					
6 Jet Blast	A		A		A		A		A	
7 Jt. Reflection Crk	L	L, M, H	H							
8 Long. & Trans. Crk.	L	L, M, H	H					L	L, M	
9 Oil Spillage	A		A	A						
10 Patching	L	M	H*	H*						*Replace Patch
11 Polished Agg.	A								A	
12 Raveling/ Weathering	L		H				L, M	L	M, H	
13 Rutting	L		M, H	M, H	M, H					
14 Shoving	L		M, H							
15 Slippage Crk.	A		A							
16 Swell	L			M, H						

A = distress types having one severity level
L = distress at low severity
M = distress at medium severity
H = distress at high severity
# = Fog Seal shall not be used on runway pavements without prior approval by Command Pavement Engineer

JOINTED-CONCRETE-SURFACED PAVEMENTS

1. Overlay with unbonded, partially bonded, or fully bonded Portland cement concrete (rigid overlay).

2. Overlay with all-bituminous or flexible overlay (non-rigid overlay).

3. Portland cement concrete pavement recycling[8] - a process by which an existing portland cement concrete pavement is processed into aggregate and sand sizes, then used in place of, or in some instances with additions of conventional aggregates and sand, into a new mix and placed as a new portland cement concrete pavement.

4. Pulverize existing surface in-place, compact with heavy rollers, place aggregate on top, and overlay.

5. Replace keel section, i.e., remove central portion of pavement feature (subjected to much higher percentage of traffic coverages than rest of pavement width) and replace with new pavement structure.

6. Reconstruct by removing existing pavement structure and replacing with a new one.

7. Grind off thin layer of surface if predominant distress is scaling or other surface distresses; overlay may or may not be applied.

8. Groove surface if poor skid resistance/hydroplaning potential is the main reason for overall M&R.

ASPHALT- OR TAR-SURFACED PAVEMENTS

1. Overlay with all-bituminous or flexible overlay.

2. Overlay with Portland cement concrete (rigid overlay).

3. Hot-mix asphalt pavement recycling[9] - one of several methods where the major portion of the existing pavement structure including, in some cases, the underlying untreated base material, is removed, sized and mixed hot with added asphalt cement at a central plant. The process may also include the addition of new aggregate and/or a softening agent. The finished product is a hot-mix asphalt base, binder, or surface course.

4. Cold-mix asphalt pavement recycling[10] - one of several methods where the entire existing pavement structure including, in some cases,

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[8]Federal Highway Administration, Initiation of National Experimental and Evaluation Program (NEEP) Project No. 22, Pavement Recycling ([FHWA] Notice N 5080.64 June 3, 1977).
[9]Ibid.
[10]Ibid.

the underlying untreated base material, is processed in-place or removed and processed at a central plant. The materials are mixed cold and can be reused as an aggregate base, or asphalt and/or other materials can be added during mixing to provide a higher strength base. This process requires that an asphalt surface course or surface seal coat be used.

5. Asphalt pavement surface recycling[11] - one of several methods where the surface of an existing asphalt pavement is planed, milled, or heated in place. In the latter case, the pavement may be scarified, remixed, relaid and rolled. Additionally, asphalts, softening agents; minimal amounts of new asphalt hot-mix, aggregates, or combinations of these may be added to obtain desirable mixture and surface characteristics. The finished product may be used as the final surface or may, in some instances, be overlayed with an asphalt surface course.

6. Apply a porous friction course to restore skid resistance and eliminate hydroplaning potential.

7. Replace keel section, i.e., remove central portion of pavement feature (subjected to much higher percentage of traffic coverage than rest of pavement width) and replace with new pavement structure.

8. Reconstruct by removing existing pavement structure and replacing with a new one.

GUIDELINES FOR SELECTION OF M&R CATEGORY

Selecting the proper M&R category (i.e., routine [preventive/localized], major, or overall) for a given pavement feature is a major decision that requires many years of experience in pavement maintenance and repair. The selection should preferably be based on the collective judgment of many experienced engineers and comprehensive economic analyses to eliminate personal biases and arrive at the best solution. The decision depends on many factors discussed in Section IV, including existing pavement condition (PCI), rate of pavement deterioration, causes of deterioration, pavement load carrying capacity, hydroplaning potential, previous M&R, and past/current/future traffic, mission, and costs. In many cases, a group of experienced pavement engineers will agree on a recommended M&R category. In many others, however, disagreement will occur, and thorough examination of pavement condition evaluation and a comprehensive economic analysis will be required to select the correct M&R category and the optimum M&R alternative.

The following paragraphs describe the development of guidelines for selecting an M&R category for an airfield pavement feature based on its PCI. This explanation is followed by a step-by-step procedure for identifying feasible alternatives through examination of a pavement condition evaluation. Section VI of this report describes an economic analysis procedure developed to assist the pavement engineer in selecting the optimum M&R alternative among all feasible alternatives.

[11] Ibid.

The correlation of the PCI with M&R categories was based on results obtained from 37 airfield pavement features using the collective judgment of 10 experienced pavement engineers. The M&R guidelines are for only the future 2 years, since this represents a period of time over which future estimates are reasonably reliable, and about 2 years lead is required to develop and approve plans for overall M&R. The 37 pavement features consisted of primary runways, taxiways, and aprons surveyed by CERL engineers during the past 2 years. They represent a wide variety of climates, traffic, ages, and structure. Eighteen of the features were asphalt- or tar-surfaced pavements, and 19 were jointed concrete. During the field surveys, all existing distress was measured, 35-mm color slides taken, pavement structure and age determined, and primary aircraft identified. This information was given to the 10 experienced engineers to aid them in making M&R decisions (see Appendix G). Since at least two to four of the raters had previously examined the pavement feature, additional information was also available. Table 10 shows a summary of the features and the percentage of engineers recommending the routine, major, or overall category of M&R. Also shown in the table are the PCI and condition rating for each feature. It should be emphasized the calculated PCIs for the features were not available to the engineers when recommending M&R requirements.

An analysis was conducted using these data. Figure 27 shows a plot of the PCI for each pavement feature versus the percentage of engineers recommending routine, major, or overall M&R within the next 2 years of the pavement's life. For any given feature, the sum of the percentage of engineers recommending the three M&R categories adds up to 100 percent. Another way of plotting the data is shown in Figure 28, in which the percentage of raters choosing routine, major, and overall M&R is computed for each condition rating zone. These results show that the higher the PCI, the greater the percentage of engineers selecting only routine M&R. The lower the PCI, the greater the percentage choosing overall M&R. In the middle of the PCI scale (40 to 70), there is a lack of consensus as to which to recommend. Major M&R is chosen most often from 25 to 70, but rarely above or below these limits.

Based on these results, four M&R zones were established to provide guidelines for selection of M&R. The four zones conveniently fit the condition rating zones used with the PCI, as shown in Figure 29. The four zones are described below.

1. Routine M&R (R-Zone). This zone includes all pavement features having PCIs between 71 and 100, or a condition rating of very good or excellent. Figures 27 and 28 show that only routine M&R was recommended by nearly all engineers for the next 2 years for pavement features within this range. The specific routine M&R methods are determined based on distress types and severities, as presented in Tables 8 and 9. Major or overall M&R would only be recommended in exceptional cases where the pavement condition evaluation indicates one or more of the following:

a. Load-associated distress accounts for a majority of the deduct values, and the load carrying capacity is deficient as indicated by a yes rating on Figure 26.

TABLE 10. SUMMARY OF AIRFIELD PAVEMENT FEATURES USED FOR CORRELATING PCI VERSUS M&R CATEGORY

Feature No.	Feature Use	Surface Type	Percent Engineers Recommending Routine M&R	Major M&R	Overall M&R	PCI	Rating
1	Primary R/W	A/T	100	0	0	77	Very Good
2	Primary R/W	A/T	100	0	0	86	Excellent
3	Primary R/W	JC	100	0	0	59	Good
4	Primary R/W	JC	100	0	0	55	Fair
5	Primary R/W	JC	60	0	40	67	Good
6	Primary R/W	A/T	90	0	10	73	Very Good
7	Primary R/W	JC	100	0	0	85	Very Good
8	Primary R/W	A/T	90	10	0	84	Very Good
9	Primary R/W	A/T	90	10	0	68	Good
10	Primary R/W	JC	100	0	0	80	Very Good
11	Primary R/W	JC	100	0	0	79	Very Good
12	Primary R/W	A/T	0	0	100	20	Very Poor
13	Primary R/W	A/T	55	34	11	47	Fair
14	Primary R/W	A/T	10	40	50	42	Fair
15	Primary R/W	JC	10	50	40	42	Fair
16	Primary R/W	JC	30	30	40	59	Good
17	Primary R/W	A/T	66	34	0	51	Fair
18	Primary R/W	JC	100	0	0	74	Very Good
19	Primary Taxiway	JC	80	20	0	60	Good

TABLE 10. SUMMARY OF AIRFIELD PAVEMENT FEATURES USED FOR CORRELATING PCI VERSUS M&R CATEGORY (CONCLUDED)

Feature No.	Feature Use	Surface Type	Percent Engineers Recommending: Routine M&R	Major M&R	Overall M&R	PCI	Rating
20	Primary Taxiway	A/T	0	20	80	35	Poor
21	Primary Taxiway	A/T	66	0	34	63	Good
22	Primary Taxiway	A/T	70	20	10	49	Fair
23	Primary Taxiway	A/T	20	0	80	48	Fair
24	Primary Taxiway	A/T	70	30	0	65	Good
25	Primary Taxiway	A/T	0	0	100	12	Very Poor
26	Primary Taxiway	A/T	0	0	100	17	Very Poor
27	Primary Taxiway	JC	11	61	28	32	Fair
28	Primary Taxiway	JC	100	0	0	68	Good
29	Primary Taxiway	JC	0	0	100	5	Failed
30	Primary Apron	JC	100	0	0	76	Very Good
31	Primary Apron	JC	10	10	80	54	Fair
32	Primary Apron	JC	90	10	0	65	Good
33	Primary Apron	JC	20	40	40	39	Poor
34	Primary Apron	JC	80	20	0	55	Fair
35	Primary Apron	A/T	90	10	0	63	Good
36	Primary Apron	JC	0	25	75	18	Very Poor
37	Primary Apron	JC	100	0	0	95	Excellent

A/T - Asphalt/Tar
JC - Jointed Concrete

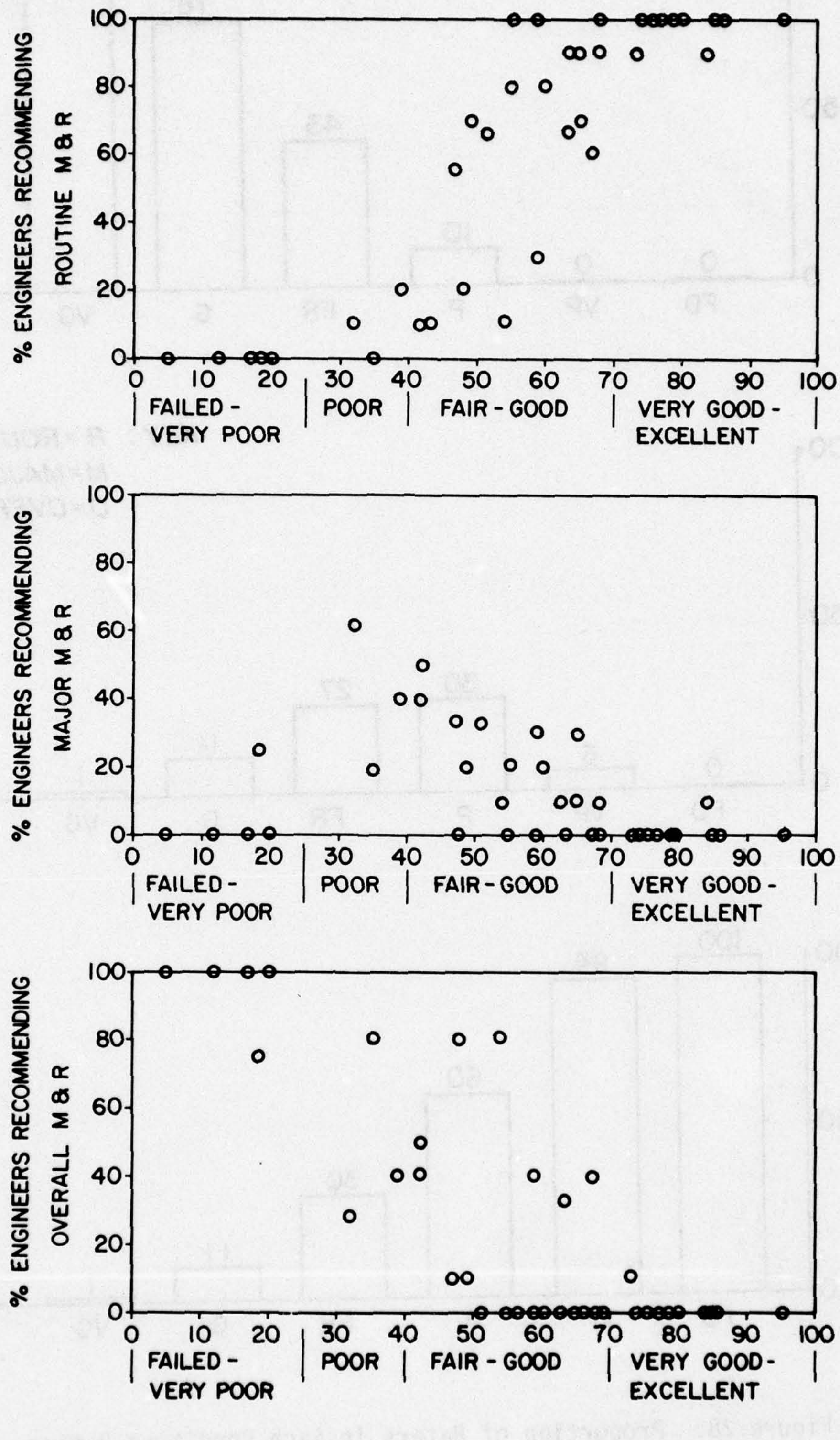

Figure 27. Plot of PCI Versus Percent Engineers Recommending Overall, Major, and Routine M&R

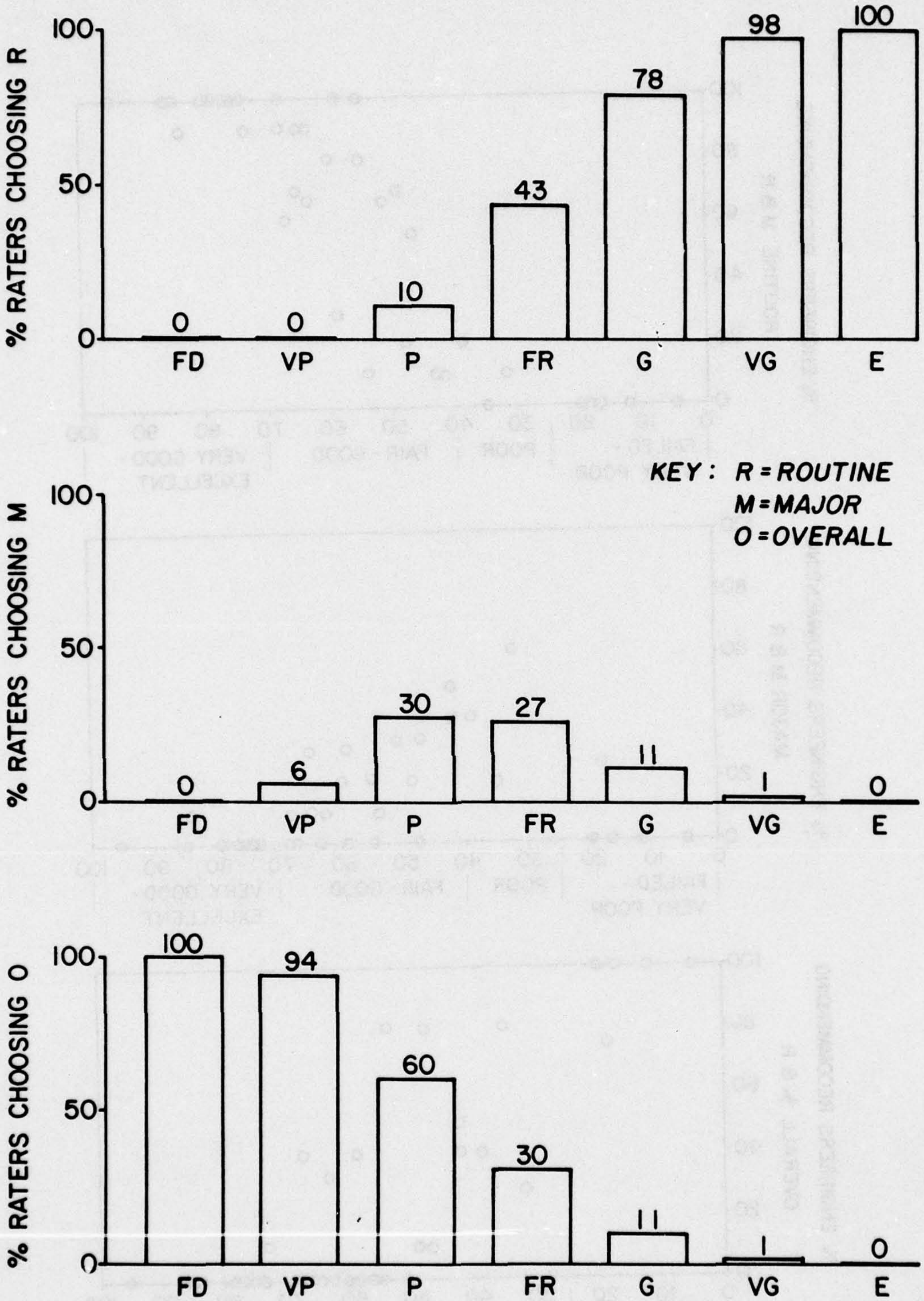

Figure 28. Proportion of Raters in Each Condition Rating Zone

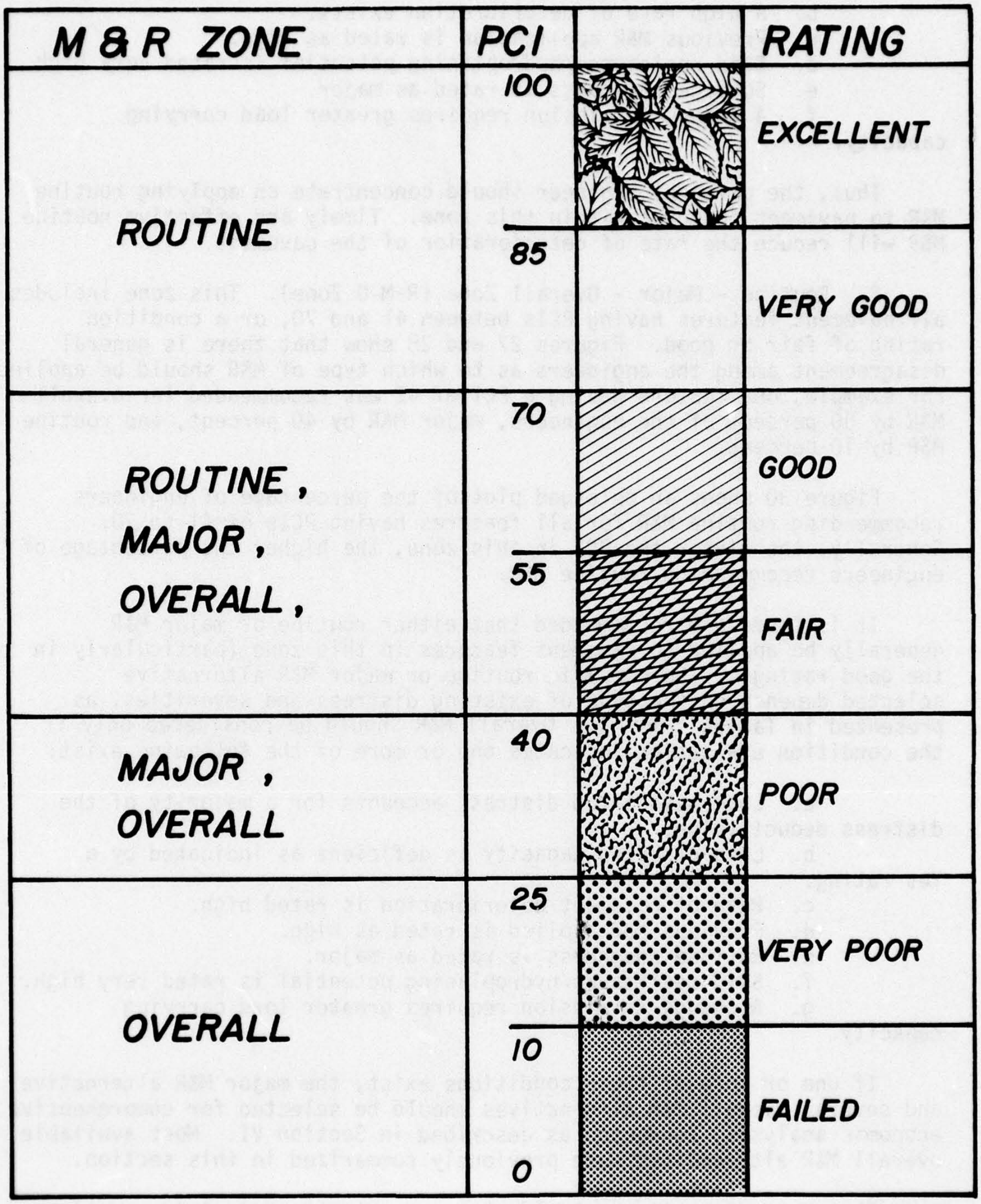

Figure 29. Correlation of M&R Zones with PCI and Condition Rating

b. A high rate of deterioration exists.
c. Previous M&R application is rated as high.
d. Skid resistance/hydroplaning potential is rated very high.
e. Surface roughness is rated as major.
f. A change in mission requires greater load carrying capacity.

Thus, the pavement engineer should concentrate on applying routine M&R to pavement features within this zone. Timely and effective routine M&R will reduce the rate of deterioration of the pavement.

2. Routine - Major - Overall Zone (R-M-O Zone). This zone includes all pavement features having PCIs between 41 and 70, or a condition rating of fair or good. Figures 27 and 28 show that there is general disagreement among the engineers as to which type of M&R should be applied. For example, one feature having a PCI of 42 was recommended for overall M&R by 50 percent of the engineers, major M&R by 40 percent, and routine M&R by 10 percent.

Figure 30 shows an enlarged plot of the percentage of engineers recommending routine M&R for all features having PCIs of 41 to 70. Generally, the higher the PCI in this zone, the higher the percentage of engineers recommending routine M&R.

It is therefore recommended that either routine or major M&R generally be applied to pavement features in this zone (particularly in the good rating). The specific routine or major M&R alternative selected depends on the type of existing distress and severities, as presented in Tables 8 and 9. Overall M&R should be considered only if the condition evaluation indicates one or more of the following exist:

a. Load-associated distress accounts for a majority of the distress deduct value.
b. Load carrying capacity is deficient as indicated by a Yes rating.
c. Rate of pavement deterioration is rated high.
d. Previous M&R applied is rated as high.
e. Surface roughness is rated as major.
f. Skid resistance/hydroplaning potential is rated very high.
g. A change in mission requires greater load carrying capacity.

If one or more of these conditions exist, the major M&R alternative and several overall M&R alternatives should be selected for comprehensive economic analysis, conducted as described in Section VI. Most available overall M&R alternatives were previously summarized in this section.

The pavement engineer should also concentrate on applying routine M&R to pavement features within this zone. Timely, effective routine M&R will reduce the rate of deterioration of the pavement.

3. Major - Overall Zone (M-O Zone). This zone includes all pavement features having PCIs between 26 and 40, or a condition rating of

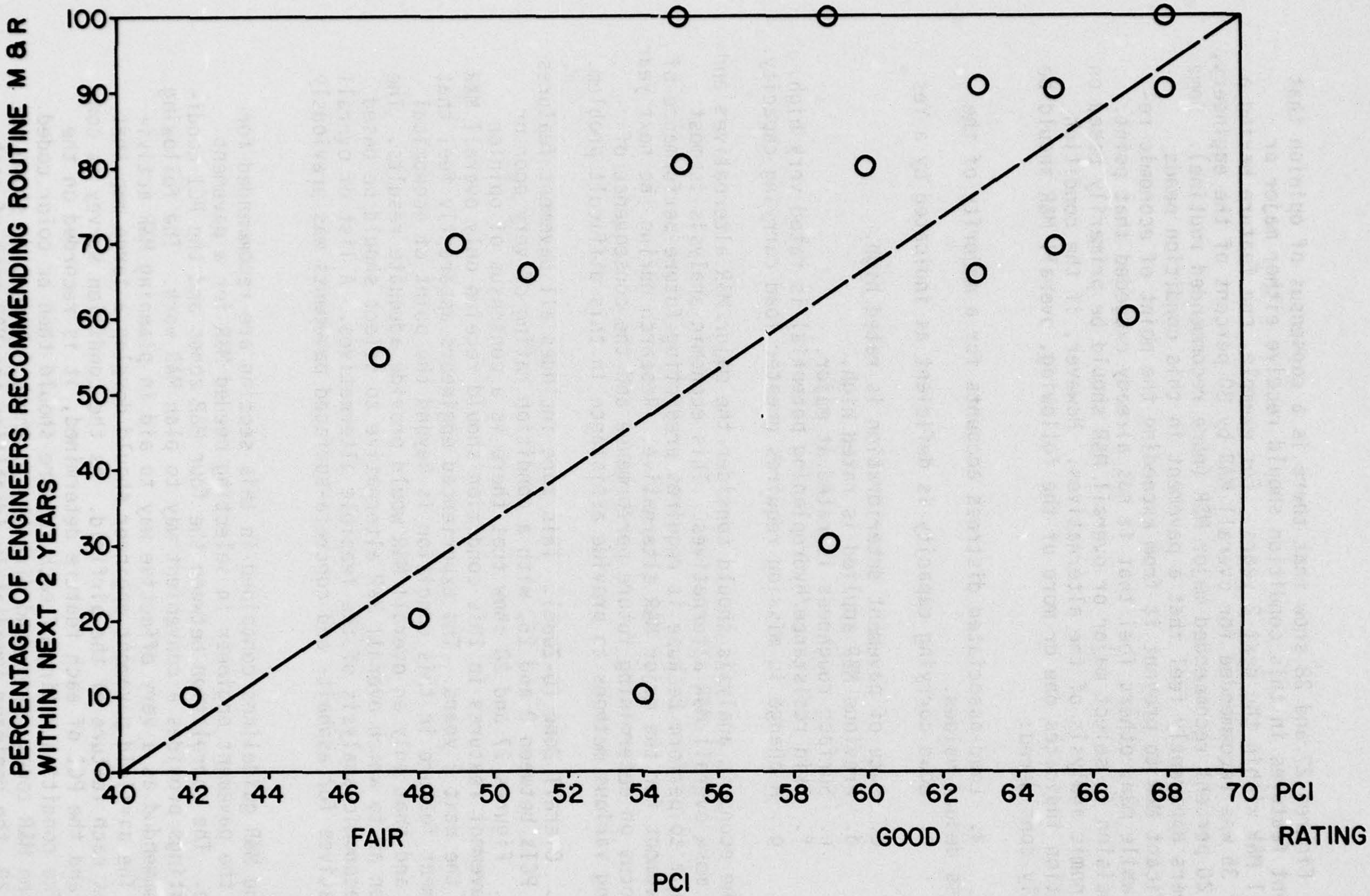

Figure 30. Mean PCI Versus Percentage of Engineers Recommending Routine M&R

poor. Figures 27 and 28 show that there is a consensus of opinion that pavement features in this condition should receive either major or overall M&R within the next 2 years. For example, one feature having a PCI of 35 was recommended for overall M&R by 80 percent of the engineers, while 20 percent recommended major M&R (none recommended routine). Some engineers apparently feel that a pavement in this condition needs significant M&R to prevent it from exceeding the point of economic repair, while many others feel that it has already exceeded that point. The decision to select major or overall M&R should be primarily based on an economic analysis of the alternatives. However, if the condition evaluation indicates one or more of the following, overall M&R should be strongly considered:

a. Load-associated distress accounts for a majority of the distress deduct values.

b. Load carrying capacity is deficient as indicated by a Yes rating.

c. Rate of pavement deterioration is rated high.

d. Previous M&R applied is rated high.

e. Surface roughness is rated at major.

f. Skid resistance/hydroplaning potential is rated very high.

g. A change in mission requires greater load carrying capacity.

The economic analysis should consider the major M&R alternatives and one or more overall M&R alternatives. This economic analysis is most difficult to perform because it requires predicting future performance of the pavement for the major M&R alternative. Research during the next year will focus on determining future performance and the consequence of applying various methods to provide assistance in this difficult problem.

4. Overall Zone (O-Zone). This zone includes all pavement features having PCIs between 0 and 25, with a condition rating of very poor or failed. Figures 27 and 28 show that there is a consensus of opinion that pavement features in this condition should receive only overall M&R within the next 2 years. The experienced engineers apparently feel that a pavement feature in this condition is beyond the point of economical repair and that only an overall M&R would provide adequate results. The decision as to which overall M&R alternative to select should be based on an economic analysis of the feasible alternatives. A list of overall alternatives for asphalt- and concrete-surfaced pavements was previously given.

The M&R guidelines contained in this section are recommended for use by the pavement engineer in selecting needed M&R for a pavement feature. The correlation between the four M&R zones and the PCI condition ratings provides a convenient way to plan M&R work. The following is recommended as a very effective way to aid in planning M&R activities. The airfield pavement engineer should develop a large map that outlines each feature of the airfield. As the condition survey is conducted and the PCI of each feature determined, it is recorded on the map. The condition rating of each feature should then be color coded. Since the M&R zones correspond directly to these ratings, as shown in Figure 29, the engineer immediately identifies the M&R zone of each feature of the airfield.

SECTION VI

ECONOMIC ANALYSIS OF M&R ALTERNATIVES

Based on the results of pavement condition evaluation (Section IV) and the guidelines for M&R selection (Section V), the engineer may need to consider more than one M&R alternative for restoring the pavement's structural integrity and operational condition. Selection of the best alternative often requires performing an economic analysis to compare the costs of all feasible alternatives. This section presents an economic analysis procedure. The procedure, which compares M&R alternatives based on total present worth, consists of the following steps:

1. An economic analysis period (in years) is selected. The period generally used in pavement analysis is in the range of 5 to 20 years, depending on future use of the feature (abandonment, change of mission, etc.). Using the present worth method of economic analysis, the alternatives must be compared over the same number of years. Thus all alternatives must have equal life.

2. Interest and inflation* rates to be used for calculating the present cost are selected. If the interest and inflation rates are equal, the present cost will be equal to the total cost spent over the analysis period. If the interest rate exceeds the inflation rate, the present cost will be less than the total cost spent over the analysis period and vice versa. Table 11 illustrates the significance of the interest and inflation rates. If the interest rate exceeds the inflation rate by 5 percent, 1000 dollars spent 10 years from now is equivalent to 645 dollars at the present time, i.e., if 645 dollars is saved now at an interest rate 5 percent higher than the inflation rate, this 645 dollars will have a purchasing power of 1000 dollars 10 years from now. On the other hand, if the inflation rate exceeds the interest rate by 5 percent, 1587 dollars must be saved now to have a purchasing power of 1000 dollars 10 years from now.

3. The annual M&R cost for each M&R alternative is estimated for every year work is planned during the analysis period. The cost estimates should be based on current prices.

4. The salvage value of an M&R alternative is the value or worth of the pavement at the end of the analysis period. It can be determined by subtracting the cost of constructing a new pavement structure over the subgrade (assuming no pavement exists) from the cost of rehabilitating or reconstructing the existing pavement structure. This difference in costs, then, gives the value of the existing pavement (which may be a negative value if it is badly deteriorated). The major difficulty lies in determining the rehabilitation or reconstruction cost, since the exact condition of the pavement is unknown. Due to the many uncertainties involved, and especially if it is felt that there is only minimal potential difference between salvage values of the alternatives, they can

*If used, the inflation rate should be based upon recommendations from the Air Force.

be considered to be equal and need not be considered in the analysis. If a salvage value is assigned, however, it should be discounted to its present worth based on interest and inflation rates.

5. The total present worth for each M&R alternative is calculated as follows:

$$\text{Total present worth} = \sum_{i=1} C_i \times f_i - SVf_i \qquad \text{[Equation 4]}$$

where n = number of years in the analysis period

C_i = M&R cost for year i based on current costs

f_i = present worth factor for i^{th} year that is function of the interest and inflation rates (Table 11).

After completion of these basic steps, comparison of the present worth for all M&R alternatives will assist the pavement engineer in selecting the most economic repair alternative. Figure 31 shows a format designed to simplify the use of the procedure for calculating the present worth for each M&R alternative.

It should be emphasized, however, that a considerable number of predictions and assumptions must be made to perform the analysis. The engineer must therefore use judgment in selecting the best inputs and use the results of the analysis as an aid in decision-making. The following guidelines are presented to assist the engineer in selecting inputs to the analysis procedure for each major input:

1. Economic analysis period. The economic analysis period is set equal to the alternative with the longest life (time to drop to minimum acceptable condition). M&R alternatives having lives less than the longest alternative must be maintained in an acceptable condition for the rest of the analysis period and the costs determined. For example, if alternative A is performing major M&R to last a 15-year period and alternative B is concrete reconstruction designed for 25 years, additional M&R must be applied to alternative A at year 15 to make it last 25 years. The costs for this extension in life must be considered in the cost analysis.

2. Selecting interest and inflation rates. Interest and inflation rates can be based on current economic trends; certain rates may be recommended by Air Force headquarters.

3. Annual cost of M&R. The trend of the amount of M&R required for a feature can be estimated from past records of similar features, or the engineer may have observed similar situations in the past which represent the feature under consideration. M&R prices should all be based on current prices.

TABLE 11. PRESENT WORTH FACTORS FOR DIFFERENT INTEREST AND INFLATION RATES

Year	Interest Rate - Inflation Rate										
	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.111	1.099	1.087	1.075	1.064	1.053	1.042	1.031	1.020	1.010	1.000
3	1.235	1.208	1.181	1.156	1.132	1.108	1.085	1.063	1.041	1.020	1.000
4	1.372	1.327	1.284	1.243	1.204	1.166	1.130	1.096	1.062	1.031	1.000
5	1.524	1.458	1.396	1.337	1.281	1.228	1.177	1.130	1.084	1.041	1.000
6	1.694	1.602	1.517	1.437	1.363	1.292	1.226	1.165	1.106	1.052	1.000
7	1.882	1.761	1.649	1.546	1.450	1.360	1.278	1.201	1.129	1.062	1.000
8	2.091	1.935	1.793	1.662	1.542	1.432	1.331	1.238	1.152	1.073	1.000
9	2.323	2.127	1.948	1.787	1.641	1.507	1.386	1.276	1.175	1.084	1.000
10	2.581	2.337	2.118	1.922	1.745	1.587	1.444	1.315	1.199	1.095	1.000
11	2.868	2.568	2.302	2.066	1.857	1.670	1.504	1.356	1.224	1.106	1.000
12	3.187	2.822	2.502	2.222	1.975	1.758	1.567	1.398	1.249	1.117	1.000
13	3.541	3.101	2.720	2.389	2.101	1.851	1.632	1.441	1.274	1.128	1.000
14	3.934	3.408	2.956	2.569	2.235	1.948	1.700	1.486	1.300	1.140	1.000
15	4.371	3.745	3.213	2.762	2.378	2.051	1.771	1.532	1.327	1.151	1.000
16	4.857	4.115	3.493	2.970	2.530	2.158	1.845	1.579	1.354	1.163	1.000
17	5.397	4.522	3.797	3.194	2.691	2.272	1.922	1.628	1.382	1.174	1.000
18	5.996	4.969	4.127	3.434	2.863	2.392	2.002	1.678	1.410	1.186	1.000
19	6.662	5.461	4.486	3.692	3.046	2.518	2.085	1.730	1.439	1.198	1.000
20	7.403	6.001	4.876	3.970	3.240	2.650	2.172	1.784	1.468	1.210	1.000
21	8.225	6.594	5.300	4.269	3.447	2.790	2.262	1.839	1.498	1.223	1.000
22	9.139	7.247	5.760	4.590	3.667	2.936	2.357	1.896	1.528	1.235	1.000
23	10.155	7.963	6.261	4.936	3.901	3.091	2.455	1.954	1.560	1.247	1.000
24	11.283	8.751	6.806	5.308	4.150	3.254	2.557	2.015	1.591	1.260	1.000
25	12.537	9.616	7.398	5.707	4.415	3.425	2.664	2.077	1.624	1.273	1.000
26	13.930	10.567	8.041	6.137	4.697	3.605	2.775	2.141	1.657	1.286	1.000
27	15.477	11.612	8.740	6.598	4.997	3.795	2.890	2.208	1.691	1.299	1.000
28	17.197	12.761	9.500	7.095	5.316	3.995	3.011	2.276	1.725	1.312	1.000
29	19.108	14.023	10.326	7.629	5.655	4.205	3.136	2.346	1.761	1.325	1.000
30	21.231	15.410	11.224	8.203	6.016	4.426	3.267	2.419	1.797	1.338	1.000

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TABLE 11. PRESENT WORTH FACTORS FOR DIFFERENT INTEREST AND INFLATION RATES (CONCLUDED)

Year	Interest Rate - Inflation Rate									
	1	2	3	4	5	6	7	8	9	10
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	.990	.980	.971	.962	.952	.943	.935	.926	.917	.909
3	.980	.961	.943	.925	.907	.890	.873	.857	.842	.826
4	.971	.942	.915	.889	.864	.840	.816	.794	.772	.751
5	.961	.924	.888	.855	.823	.792	.763	.735	.708	.683
6	.951	.906	.863	.822	.784	.747	.713	.681	.650	.621
7	.942	.888	.837	.790	.746	.705	.666	.630	.596	.564
8	.933	.871	.813	.760	.711	.665	.623	.583	.547	.513
9	.923	.853	.789	.731	.677	.627	.582	.540	.502	.467
10	.914	.837	.766	.703	.645	.592	.544	.500	.460	.424
11	.905	.820	.744	.676	.614	.558	.508	.463	.422	.386
12	.896	.804	.722	.650	.585	.527	.475	.429	.388	.350
13	.887	.788	.701	.625	.557	.497	.444	.397	.356	.319
14	.879	.773	.681	.601	.530	.469	.415	.368	.326	.290
15	.870	.758	.661	.577	.505	.442	.388	.340	.299	.263
16	.861	.743	.642	.555	.481	.417	.362	.315	.275	.239
17	.853	.728	.623	.534	.458	.394	.339	.292	.252	.218
18	.844	.714	.605	.513	.436	.371	.317	.270	.231	.198
19	.836	.700	.587	.494	.416	.350	.296	.250	.212	.180
20	.828	.686	.570	.475	.396	.331	.277	.232	.194	.164
21	.820	.673	.554	.456	.377	.312	.258	.215	.178	.149
22	.811	.660	.538	.439	.359	.294	.242	.199	.164	.135
23	.803	.647	.522	.422	.342	.278	.226	.184	.150	.123
24	.795	.634	.507	.406	.326	.262	.211	.170	.138	.112
25	.788	.622	.492	.390	.310	.247	.197	.158	.126	.102
26	.780	.610	.478	.375	.295	.233	.184	.146	.116	.092
27	.772	.598	.464	.361	.281	.220	.172	.135	.106	.084
28	.764	.586	.450	.347	.268	.207	.161	.125	.098	.076
29	.757	.574	.437	.333	.255	.196	.150	.116	.090	.069
30	.749	.563	.424	.321	.243	.185	.141	.107	.082	.063

M & R ALTERNATIVE ____________________

____

ANALYSIS PERIOD ______ YEARS INTEREST RATE ______ %

INFLATION RATE ______ %

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
		TOTAL		$

SALVAGE VALUE = = $ ____________________

PRESENT WORTH = $ ____________________

Figure 31. Calculation Sheet for Determining Present Worth of an M&R Alternative

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DEVELOPMENT OF A PAVEMENT MAINTENANCE MANAGEMENT SYSTEM. VOLUME--ETC(U)
SEP 77 M Y SHAHIN, M I DARTER, S D KOHN

UNCLASSIFIED CERL-TR-C-76-VOL-3 CEEDO-TR-77-44-VOL-3 NL

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The following example illustrates the use of the procedure. A 25 year old asphalt taxiway is 100 feet wide and 1150 feet long. The pavement structure of the taxiway consists of a sandy subgrade (CBR = 35), silty sand base course (9 inch, CBR = 40), and 5 inch asphalt concrete surface. A PCI condition survey of the feature showed that the central 50 feet of the taxiway is in a poor condition (PCI = 36) and the outside 50 feet is in a fair condition (PCI = 51). Based on the traffic mission, the pavement engineer is considering the following three alternatives:

1. Alternative A - Perform localized repair, place an aggregate seal, overlay with 3 inches AC on the central 50 feet and taper to 1 inch at the edge.

2. Alternative B - Recycle top 5 inches of central 50 feet and reuse as a base course and overlay with 4 inches AC. Perform localized repair and apply rejuvinator on the outside 50 feet.

3. Alternative C - Remove top 5 inches of central 50 feet, add 1 inch aggregate, stabilize 6 inches of base coarse with cement, and overlay with 4 inches AC. Perform localized repair and apply rejuvinator on the outside 50 feet.

Tables 12, 13, and 14 show the calculation of the total present worth for each of the alternatives. The analysis indicates that alternative A is the most economical. The engineer should use this result as an aid in making the final decision, which may consider other factors that are not quantifiable.

The economic analysis procedure presented herein provides a tool for comparing various M&R alternatives based on present cost. Although all M&R alternatives provide pavement condition above the minimum acceptable level, they provide different levels of pavement performance and thus different levels of satisfaction. A preliminary economic analysis procedure that takes pavement performance into consideration has been developed and is presented in Appendix H.

TABLE 12. CALCULATION OF PRESENT WORTH OF ALTERNATIVE A

M & R ALTERNATIVE "A"-PARTIAL DEPTH, RUTTING AND DEPRESSION, APPLY AGGREGATE SEAL, AND OVERLAY

ANALYSIS PERIOD 20 YEARS INTEREST RATE 8 %

INFLATION RATE 6 %

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1	PARTIAL DEPTH PATCH AT			
	$19/SQ YD	19,949	1.0	19,949
1	AGGREGATE SEAL AT			
	$0.5/SQ YD	6,389	1.0	6,389
1	OVERLAY WITH AC AT			
	$35/ton	60,794	1.0	60,794
10	APPLY REJUVENATOR AT			
	$0.23/SQ YD	2,939	.837	2,460
15	APPLY REJUVENATOR AT			
	$0.23/SQ YD	2,939	.758	2,228
			TOTAL	$ 91,820

SALVAGE VALUE* = $ 0

PRESENT WORTH = $ 91,820

*THE SALVAGE VALUE IS ASSUMED TO BE EQUAL FOR ALL THREE ALTERNATIVES. THEREFORE, A VALUE OF ZERO IS USED TO SIMPLIFY CALCULATIONS.

TABLE 13. CALCULATION OF PRESENT WORTH OF ALTERNATIVE B

M & R ALTERNATIVE "B"-RECYCLE CENTER 50 FT (TOP 5 IN.) AND REUSE AS A BASE COURSE AND OVERLAY WITH 4 IN. NEW AC. APPLY REJUVENATOR ON OUTSIDE 50 FT

ANALYSIS PERIOD 20 YEARS INTEREST RATE 8 %

INFLATION RATE 6 %

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1	REMOVE 50 FT WIDE 5 IN. AC, 4 IN. BASE MATL. RECYCLE AC AND PLACE AS A BLACK BASE AT $ 7.4/SQ YD	47,277	1.0	47,277
1	OVERLAY CENTER 50 FT WIDE WITH 4 IN. AC AT $ 35/TON	48,635	1.0	48,635
1	PARTIAL DEPTH PATCH ON OUTSIDE 50 FT AT $ 19/SQ YD	527	1.0	527
1	FILL CRACKS ON OUTSIDE AT $0.25/LINEAR FEET	2,875	1.0	2,875
1	APPLY REJUVENATOR ON OUTSIDE AT $0.23/SQ YD	1,469	1.0	1,469
5	APPLY REJUVENATOR ON OUTSIDE 50 FT AT $0.23/SQ YD	1,469	.924	1,357
10	REJUVENATE AT $0.23/SQ YD	2,939	.837	2,460
15	REJUVENATE AT $0.23/SQ YD	2,939	.758	2,228
			TOTAL	$106,828

SALVAGE VALUE* = $ 0

PRESENT WORTH = $ 106,828

*THE SALVAGE VALUE IS ASSUMED TO BE EQUAL FOR ALL THREE ALTERNATIVES. THEREFORE, A VALUE OF ZERO IS USED TO SIMPLIFY CALCULATIONS.

TABLE 14. CALCULATION OF PRESENT WORTH OF ALTERNATIVE C

M & R ALTERNATIVE "C" - REMOVE CENTRAL 50 FT (5 IN.) OF AC. APPLY 1 IN. AND STABALIZE 6 IN. WITH CEMENT. OVERLAY WITH 4 IN. AC. REJUVENATE ON OUTSIDE 50 FT.

ANALYSIS PERIOD 20 **YEARS INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1	REMOVE 5 IN. AC, ADD 1 IN. AGG., AND STABALIZE 6 IN. BASE WITH CEMENT AT $6/SQ YD	38,333	1.0	38,333
1	OVERLAY CENTRAL 50 FT WITH 4 IN. AC AT $35/TON	48,635	1.0	48,635
1	AC PATCH DEPRESSION ON THE OUTSIDE AT $19/SQ YD	527	1.0	527
1	FILL CRACKS ON OUTSIDE ONLY AT $0.25/LINEAR FEET	2,875	1.0	2,875
1	APPLY REJUVENATOR ON OUTSIDE AT $0.23/SQ YD	1,469	1.0	1,469
5	APPLY REJUVENATOR ON OUTSIDE AT $0.23/SQ YD	1,469	.924	1,357
10	REJUVENATE AT $0.23/SQ YD	2,939	.837	2,460
15	REJUVENATE AT $0.23/SQ YD	2,939	.758	2,228
			TOTAL	$97,884

SALVAGE VALUE* = $ 0

PRESENT WORTH = $ 97,884

***THE SALVAGE VALUE IS ASSUMED TO BE EQUAL FOR ALL THREE ALTERNATIVES. THEREFORE, A VALUE OF ZERO IS USED TO SIMPLIFY CALCULATIONS.**

SECTION VII

EXAMPLE APPLICATION OF M&R GUIDELINES AND ECONOMIC ANALYSIS

INTRODUCTION

This section provides an example that describes the application of all the steps in determining optimum M&R requirements for a pavement feature. The steps included are data collection, condition evaluation, selection of feasible M&R alternatives, economic analysis, and selection of the optimum M&R alternative.

The pavement used in this example is a portion of a runway constructed in 1947 of plain jointed concrete. The pavement is 150 feet wide and 2760 feet long. The individual slab size is 12.5 feet by 20 feet. Figure 32 shows the slab layout for the runway.

The critical aircraft using the runway for the past 8 years has been the DC-9 (prior to that time only light load aircraft operated on the runway). The pavement is exhibiting distress which began after the DC-9 started operation on the runway. The pavement engineer is concerned about the current pavement deterioration and the amount of maintenance required.

The problem is to determine the best M&R alternative. The following subsections describe the steps used in the procedure.

STEP 1 - DATA COLLECTION

A pavement condition survey was performed on the feature in 1977 according to the guidelines presented in Volumes I and II. Prior to the actual survey, it was observed that most distress occurred within the central 50 feet (i.e., slab rows 5, 6, 7, and 8) and that all but a few of the tire rubber marks were contained in the central 75 feet (slab rows 4, 5, 6, 7, 8, and 9). The condition of rows 1 to 3 and 10 to 12 was very similar, in that they exhibited only minor distress. Therefore, the six center rows of slabs were grouped as the pavement feature to be surveyed and analyzed.

All 828 slabs in the central six slab rows of the feature were surveyed. The survey was accomplished by inspecting 46 sample units of 18 slabs each (six slabs wide and three slabs long). The entire feature was surveyed, since it was desired to have extensive information for this example. A few random samples were also obtained from the outer three rows of slabs on both sides of the runway. Pavement structure and material data were obtained from the construction plans and previous pavement evaluation data (Table 15); traffic data were obtained from traffic control personnel (Table 16).

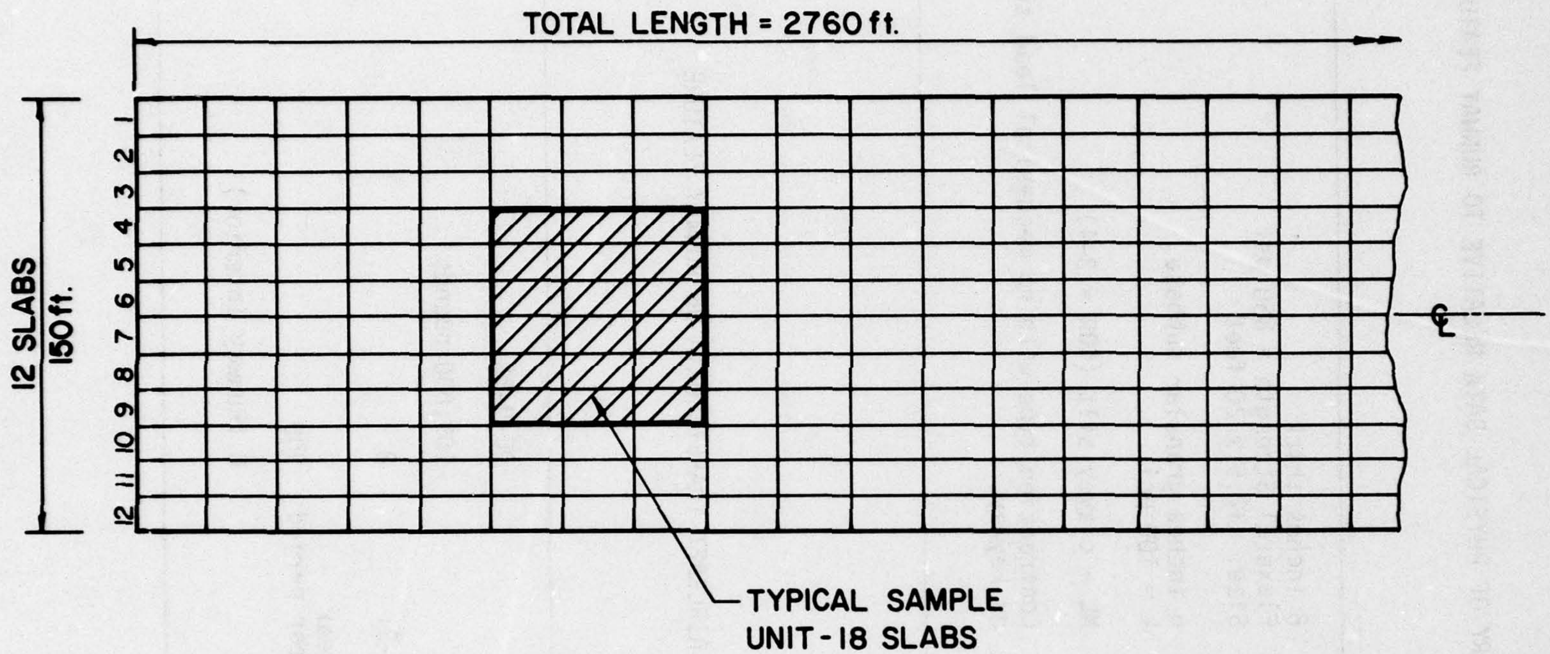

Figure 32. Layout of Runway Feature

TABLE 15. SUMMARY OF PHYSICAL DATA RELATIVE TO RUNWAY FEATURE

1.	PCC Slab:	8 inches thick Flexural Strength = 850 psi Size: 12.5 x 20 feet
2.	Subbase:	6 inches granular subbase k = 100 pci
3.	Subgrade:	ML - clayey silt (CBR = 3-4)
4.	Joints:	Contraction type with no mechanical load transfer or keyway.

TABLE 16. AIRCRAFT TRAFFIC DATA ON RUNWAY FEATURE

Major Aircraft:	DC-9-32
Gross Weight:	109,000 pounds
No. Years Used by DC-9:	8
Mean No. of Passes/year on Runway over 8 year period:	900
Type Traffic Area:	C (Runway Interior)

STEP 2 - CONDITION EVALUATION

1. Overall condition. From the condition survey data, the mean PCI was computed (for the center six rows) by averaging the PCIs of the 46 sample units. This computation resulted in a feature mean PCI of 65 and condition rating of good. The mean PCI of the outer six slabs (three rows on each edge) was 79 and the condition rating was very good.

2. Variation of condition. Comparison of the PCIs for the center six rows of slabs and the outer six rows indicates that a systematic variation in condition occurs across the runway. Thus, the initial assumption of considering the central six rows of slabs as one feature is supported by both the variation in condition and distribution of traffic. The occurrence of localized random variability was checked using Figure 18. From the figure, the minimum critical PCI is 48. A plot of the PCI along the runway (Figure 33) shows that there are three sample units below the limit, accounting for 6 percent of the total sample units. Thus, there are definite localized "bad" areas along the feature. They are, however, spread apart so that no longitudinal breakdown of the feature is necessary.

3. Rate of deterioration of pavement condition. Long-term deterioration is determined from Figure 21. Using an age of 30 years and the PCI of 65, the feature lies above the shaded (or normal) area, indicating a relatively low rate of deterioration since construction.

According to the pavement engineer, the feature has experienced considerable deterioration over the past 5 to 7 years. The PCI values from previous years are not known, so the seven-point criterion cannot be applied. Therefore, short-term deterioration was estimated by comparing the PCIs of the outer and center rows of slabs. The difference between the 79 for the outer rows and the 65 for the center rows indicates that the rate of deterioration over the past 5 to 7 years is high. This fact combined with the observations of the pavement engineer leads to the conclusion that the short-term rate of deterioration is high.

4. Distress evaluation. Table 17 summarizes the types of distress occurring within the central six slabs, along with their deduct values and the percent effect of load, climate durability, and other causes. These data show that traffic-load-associated distress accounts for 58 percent of total deduct values. Climate/durability distress amounts to 36 percent of the total deduct values. Thus, traffic-load-associated distress is causing the majority of pavement distress. Figure 22 shows a plot of load-associated distress across the runway. The concentration of distress within the center two rows of slabs corresponds well with the aircraft main gear spacing.

The pavement is located in zone I-A (soil wet all year round, low temperature) (see Appendix C for map of environmental zones). The mean precipitation is 33 inches, and approximately 5 to 10 freeze-thaw cycles occur within the pavement annually. The major distress being caused

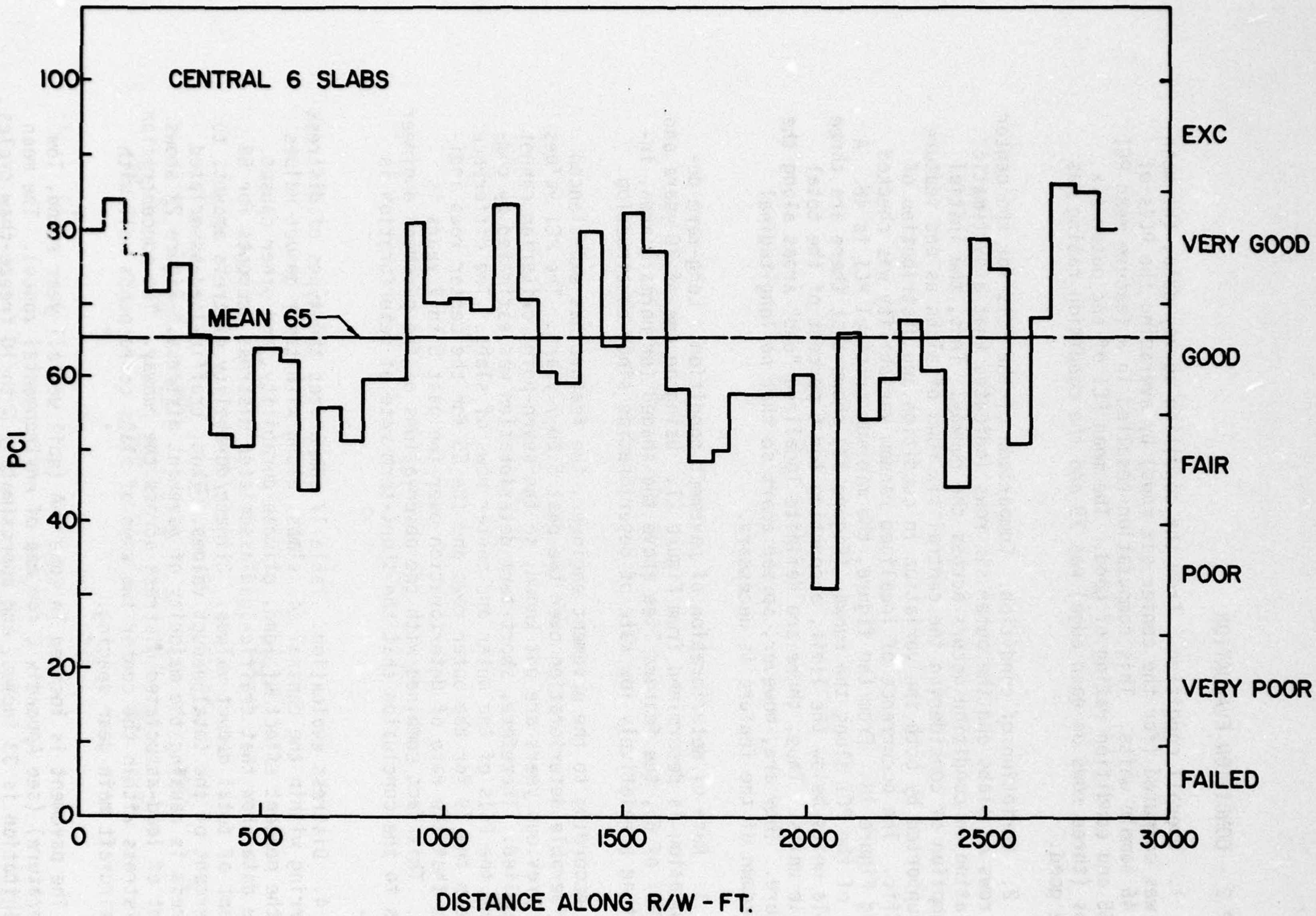

Figure 33. PCI Profile Along Runway Feature

TABLE 17. SUMMARY OF DISTRESSES OCCURRING IN RUNWAY FEATURE - CENTER SIX SLABS

Cause	Distress	Deduct Value	% Effect
Load	Corner Break	4	
	Long. & Trans. Crack	22	
	Patching > 5 square feet	5	
	Shattered Slab	6	
	Total	37	58
Climate/ Durability	"D" Cracking	2	
	Joint Seal Damage	12	
	Patching < 5 square feet	1	
	Shrinkage Crack	1	
	Joint Spalling	4	
	Corner Spalling	3	
	Total	23	36
Other	Faulting/Settlement	4	
	Total	4	6
		Total	100

and accelerated by moisture is "D" cracking of the slab. This results partly from the poor condition of joint seals which allows precipitation to freely infiltrate the joints, be absorbed into the concrete, and be subjected to freeze-thaw cycles. The effect of moisture is considered moderate, since there are several slabs with "D" cracking.

5. Load carrying capacity. The approximate number of passes of the DC-9 aircraft over the feature for the past 8 years is estimated (using data from Table 16) as:

900 passes/year x 8 years = 7200 passes.

The number of passes to initiation of cracking determined from Figure 34 using pavement data in Table 15 is about 4000. Thus, this analysis shows that a definite load carrying capacity deficiency exists. Also, analyzing the load carrying capacity using the standard methods in AFM 88-24 indicates that the gross aircraft loading of 109,000 pounds exceeds the maximum allowable gross loading for capacity operations (which is 103,900 pounds). Other aircraft using the runway are less than one-half the weight of the DC-9 and are not considered to have much effect on pavement performance.

6. Surface roughness. Since roughness-measuring equipment was not available, a subjective evaluation was made. Some pilot complaints have been received as to roughness. A number of distress types relating to roughness exist, including patching, settlement/fault, shattered slabs, spalling of joints and corners, and high-severity cracking. Based on these considerations, roughness is rated moderate.

7. Skid resistance/hydroplaning. Measurement equipment was not available and thus no evaluation could be made. The transverse slope was measured with surveying instruments and found to be about 1.1 percent down slope from the centerline. Thus, the transverse drainage slope is rated good to excellent.

8. Previous maintenance. The major type of M&R performed is patching. The extent of large patches was computed as 3.6 percent of the slabs. Thus, previous M&R is rated according to Figure 25 as high.

9. Evaluation summary. Figure 35 summarizes the condition evaluation information.

STEP 3 - SELECTION OF FEASIBLE M&R ALTERNATIVES

The PCI of the center six rows of slabs is 65. Thus, the feature is placed in the R-M-O Zone. The outer feature (three rows on each side of the center six rows) has a PCI of 79, which categorizes it in the R-Zone. Again this supports the consideration of the center six rows as a single feature.

M&R guidelines for the R-M-O Zone (Section V) state that routine or major M&R should generally be applied to pavement features in this zone,

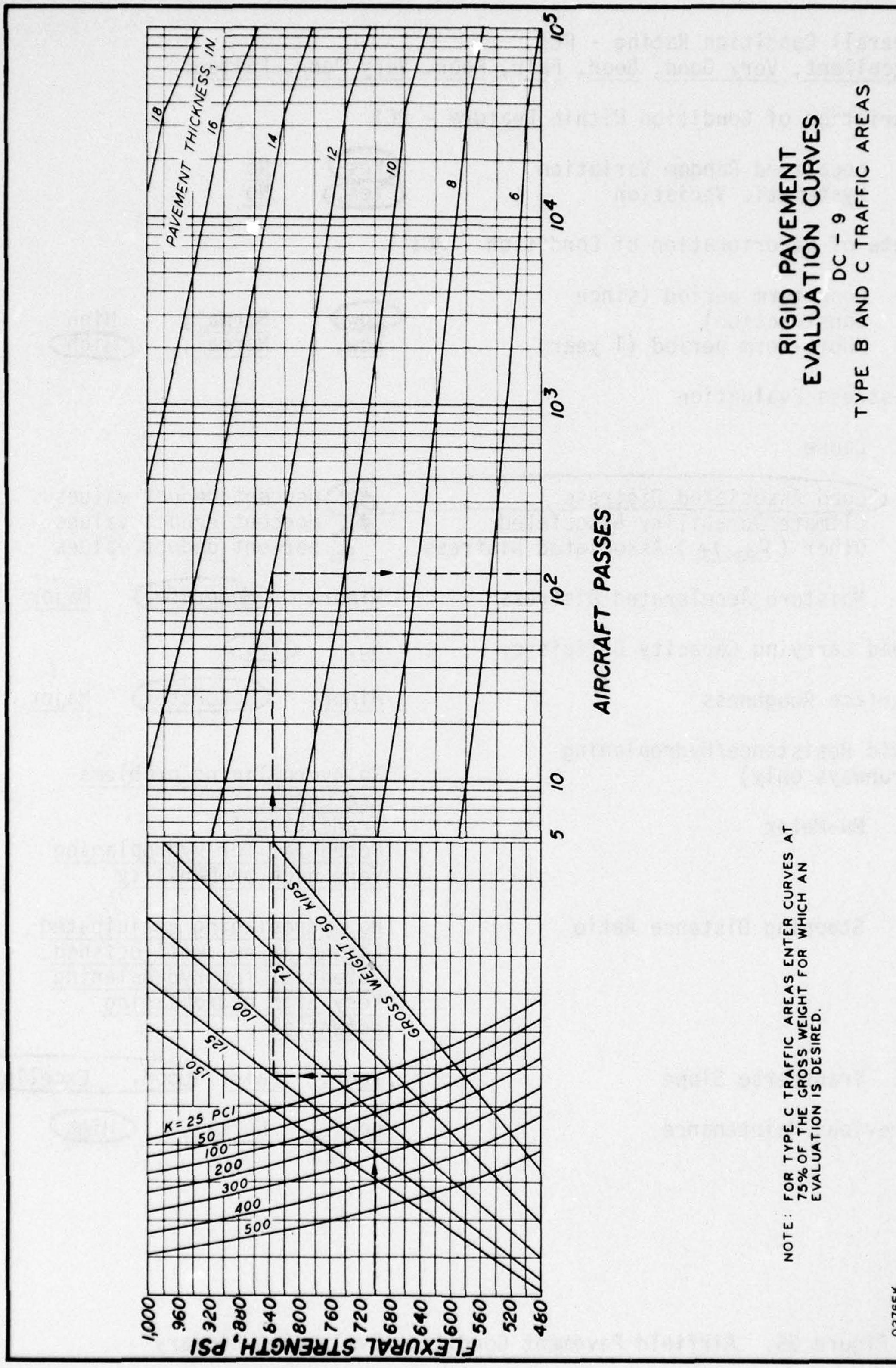

Figure 34. Rigid Pavement Evaluation Curves, DC-9, Type B and C Traffic Areas

1. Overall Condition Rating - PCI
Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

a.	Localized Random Variation	Yes,	No
b.	Systematic Variation	Yes,	No

3. Rate of Deterioration of Condition - PCI

a.	Long-term period (since construction)	Low,	Normal,	High
b.	Short-term period (1 year)	Low,	Normal,	High

4. Distress Evaluation

a. Cause

Load Associated Distress	58	percent deduct values
Climate/Durability Associated	36	percent deduct values
Other (fault) Associated Distress	6	percent deduct values

b. Moisture Accelerated Distress — Minor, Moderate, Major

5. Load Carrying Capacity Deficiency — No, Yes

6. Surface Roughness — Minor, Moderate, Major

7. Skid Resistance/Hydroplaning (runways only)

a. Mu-Meter
- No hydroplaning problems are expected
- Transitional
- Potential for hydroplaning
- Very high probability

b. Stopping Distance Ratio
- No hydroplaning anticipated
- Potential not well defined
- Potential for hydroplaning
- Very high hydroplaning potential

c. Transverse Slope — Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

Figure 35. Airfield Pavement Condition Evaluation Summary

unless the condition evaluation shows that one or more of the condition indicators is rated in a high or major category or that load-associated distress accounts for a majority of deduct values.

The evaluation summary sheet (Figure 35) shows that three of the condition indicators show this result:

1. Load-associated distress accounts for a majority of deduct values.

2. Load carrying capacity is deficient.

3. Previous maintenance is excessive and rated as high.

Therefore, the guidelines indicate that overall M&R should be strongly considered. Based on these considerations and available overall M&R alternatives given in Section V, the following feasible alternatives are selected for consideration:

1. Apply major M&R to specific distress based on recommendation in Table 9 and field condition.

2. Replace center six rows of slabs with adequate design.

3. Overlay entire width of runway with concrete.

4. Overlay entire width of runway with asphalt.

5. Perform major M&R for a few years and then perform either items 2, 3, or 4.

Each of these is considered a feasible M&R alternative. Overlaying the total width is only considered since 150 feet is the minimum allowable runway width. For the same reason, if the central six slabs are replaced, the outer slabs must also be maintained to provide acceptable operational condition.

Each alternative has its own associated costs, downtime, manpower, and equipment needs. Thus, a comprehensive economic analysis is needed to aid in selection of the best alternative.

STEP 4 - ECONOMIC ANALYSIS

A present worth type economic analysis is conducted to compare the total costs of each alternative over an analysis period. An economic analysis period of 25 years is selected because the M&R alternative having the longest life is 25 years. Figure 36 shows the percentage of slabs estimated to be replaced and their cost over the analysis period (25 years). This estimate was made using the statistical approach described in Appendix A. The statistical approach was applied to each distress type found during the condition survey to predict the percentage

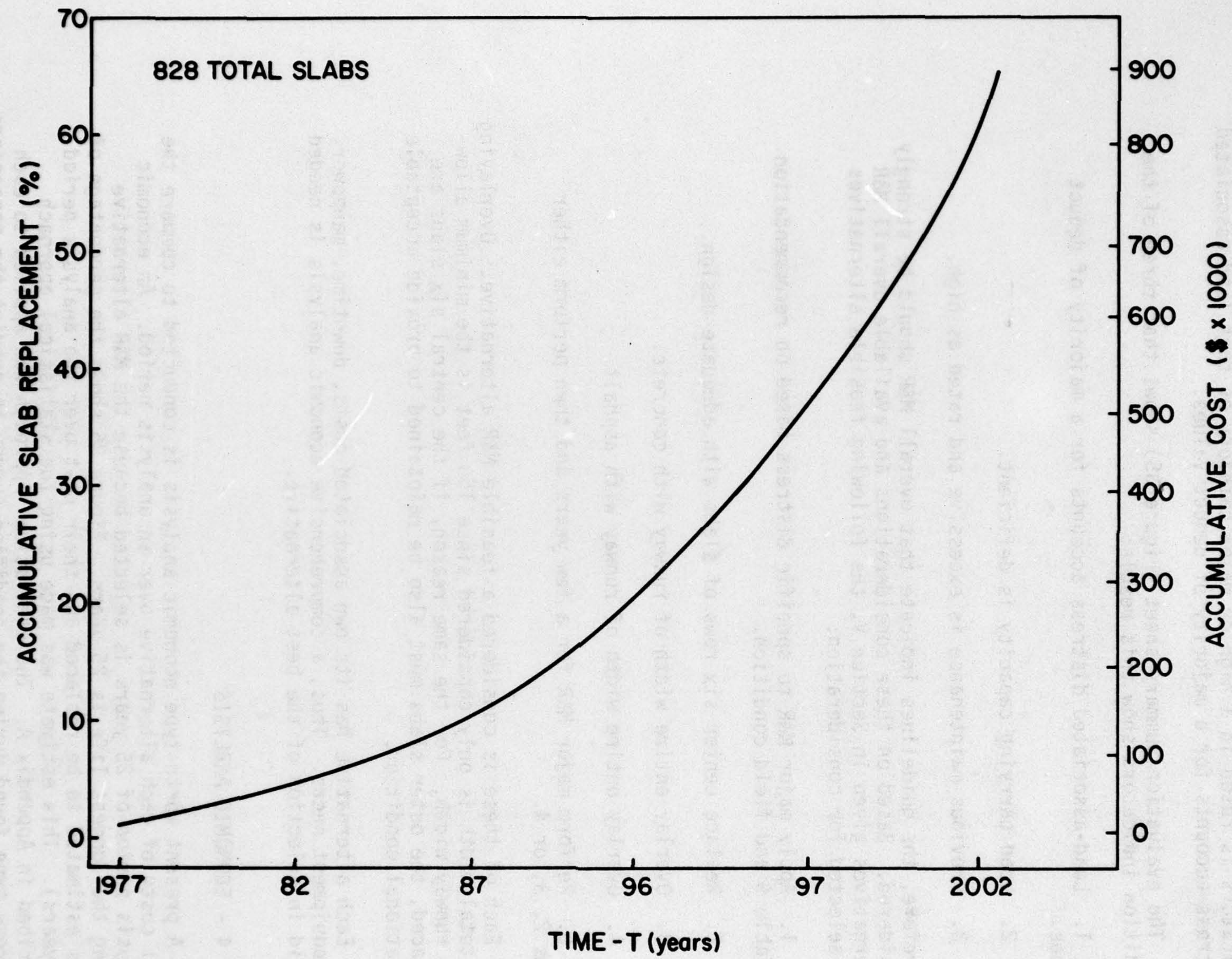

Figure 36. Prediction of Future Slab Replacement for Central Six Slabs of Runway

of slabs in the feature containing each level of severity (low, medium, and high) for the analysis period. The percentage of slabs to be replaced every year was then determined based on the policy that all medium-severity divided slabs, and shattered slabs, high-severity cracked slabs, and slabs with high-severity "D" cracking should be replaced in order to restore pavement structural integrity and surface operational condition.

Similarly, using the statistical approach, the percentage of slabs requiring small patching (less than 5 feet) was determined based on the policy that all slabs with medium- or high-severity small patches, corner spalls, and joint spalls should be repaired.

Table 18 shows the calculation of the total present worth for each of the feasible M&R alternatives. The material costs used in this table were obtained from local contractors. The thickness designs of the overlays and reconstruction were determined using the Corps of Engineers design methods.

Table 19 shows a summary comparison of all four M&R alternatives analyzed. Based on the total present worth, replacing the central six slabs in 1977 and continuing routine M&R on the outside slabs (alternative 2) is the most economic alternative. On the other hand, performing major M&R on the central six slabs and routine on the outer slabs (alternative 1) is the most expensive economic alternative.

STEP 5 - SELECTION OF OPTIMUM M&R ALTERNATIVE

It should be recognized that the economic analysis was based on several assumptions. Thus, one does not expect the numbers shown in Table 19 to be exact. The main uncertainty lies in future prediction of performance. However, the analysis does provide a reasonable relative economic comparison between the alternatives. It is clear that a strategy of major M&R is not the best alternative.

The results of the economic analysis should not be used as a rigid rule in selecting the best M&R alternative; instead, they should be used as an aid to the engineer in making the selection. For example, the engineer may decide on another alternative instead of replacing the keel (alternative 2) due to other factors not considered in the analysis, such as available funding, runway downtime to construct, and elimination of the need for routine M&R for the outer slabs required if the keel is replaced. However, based on the results considered here, the following conclusions are drawn for this example:

1. A policy of continual major M&R is the least desirable alternative. It will result in continual M&R work and runway downtime. If continued for over 2 to 3 years, it will result in very high costs (unless traffic loading is reduced).

TABLE 18. ECONOMIC ANALYSIS OF ALTERNATIVES

M & R ALTERNATIVE No. 1 APPLY MAJOR M&R TO CENTRAL 6 SLABS AND ROUTINE M&R TO OUTER SLABS

ANALYSIS PERIOD 25 YEARS INTEREST RATE 8 %

INFLATION RATE 6 %

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1977	SLAB REPLACEMENT, PARTIAL DEPTH PAT., JT. SEAL, AND CRACK SEAL	85,500	1.000	85,500
1978	SLAB REPLACEMENT, PARTIAL DEPTH PATCH, AND CRACK SEAL	11,250	0.480	11,025
1979	SAME AS 1978	17,300	0.961	16,625
1980	SAME AS 1978	23,400	0.942	22,043
1981	SAME AS 1978	28,400	0.924	26,241
1982	SAME AS 1978 PLUS JT. SEAL	60,030	0.906	54,387
1983	SAME AS 1978	46,500	0.888	41,292
1984	SAME AS 1978	48,600	0.871	42,330
1985	SAME AS 1978	66,600	0.853	56,810
1986	SAME AS 1978	74,700	0.857	62,524
1988	SAME AS 1978 PLUS JT. SEAL	111,230	0.804	89,429
1990	SAME AS 1978	99,700	0.773	77,068
1993	SAME AS 1978	115,600	0.728	84,157
1995	SAME AS 1978	129,000	0.700	90,300
1998	SAME AS 1978	143,000	0.660	94,380
			TOTAL	$854,111

SALVAGE VALUE = 188,228 X 0.622 = $ -117,078

PRESENT WORTH = $ 728,033

TABLE 18. ECONOMIC ANALYSIS OF ALTERNATIVES (CONTINUED)

M & R ALTERNATIVE No. 2 REPLACE KEEL - CENTRAL 6 SLABS IN 1977 WITH 12 IN. THICK SLAB AND SUBBASE

ANALYSIS PERIOD 25 YEARS INTEREST RATE 8 %

INFLATION RATE 6 %

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1977	INITIAL CONSTRUCTION	425,316	1.000	425,316
1978	ROUTINE M&R	1,000	0.980	980
1979	" "	1,000	0.961	961
1980	" "	1,000	0.942	942
1981	" "	1,000	0.924	924
1982	" " PLUS JT. SEAL		0.916	24,942
1983	" "	2,000	0.888	1,776
1984	" "	2,000	0.871	1,742
1985	" "	2,000	0.853	1,706
1986	" "	2,000	0.837	1,674
1988	" " PLUS JT. SEAL	28,530	0.804	22,938
1990	" "	3,000	0.773	2,319
1993	" " PLUS JT. SEAL	29,110	0.728	21,192
1995	" "	3,000	0.700	2,100
1998	" " PLUS JT. SEAL	31,000	0.660	20,460
			TOTAL	$529,972

SALVAGE VALUE = 297,782 x 0.622 = $ -185,220

PRESENT WORTH = $ 344,752

TABLE 18. ECONOMIC ANALYSIS OF ALTERNATIVES (CONTINUED)

M & R ALTERNATIVE No. 3 CONCRETE OVERLAY ENTIRE RUNWAY 10 IN. THICK IN 1977 - PARTIAL BOND

ANALYSIS PERIOD 25 YEARS INTEREST RATE 8 %

INFLATION RATE 6 %

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1977	INITIAL CONSTRUCTION	547,772	1.000	547,772
1978				0
1979				0
1980				0
1981				0
1982	JT. SEAL	25,530	0.906	23,130
1983				0
1984	ROUTINE M&R	1,000	0.871	871
1985	" "	1,000	0.853	853
1986	" "	1,000	0.837	837
1988	" " PLUS JT. SEAL	26,530	0.804	21,330
1990	" "	2,000	0.773	1,546
1993	" " PLUS JT. SEAL	29,110	0.728	21,192
1995	" "	2,000	0.700	1,400
1998	" " PLUS JT. SEAL	31,000	0.660	20,460
			TOTAL	$639,391

SALVAGE VALUE = 352,560 X 0.620 = $ -218,587

PRESENT WORTH = $ 420,804

TABLE 18. ECONOMIC ANALYSIS OF ALTERNATIVES (CONTINUED)

M & R ALTERNATIVE No. 4 ASPHALT CONCRETE OVERLAY ENTIRE RUNWAY WIDTH - 10 IN. THICK IN 1977

ANALYSIS PERIOD 25 YEARS INTEREST RATE 8 %

INFLATION RATE 6 %

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1977	INITIAL CONSTRUCTION	551,308	1.000	551,308
1978				0
1979				0
1980				0
1981	ROUTINE M&R	3,064	0.924	2831
1982	" "	3,064	0.906	2776
1983	" "	4,064	0.888	3,609
1984	" "	4,064	0.871	3,540
1985	" "	4,064	0.853	3,467
1986	" "	1,000	0.837	3,837
1988	REJUVENATOR	4,600	0.804	3,698
1990				0
1993	2IN. A OVERLAY	100,000	0.728	72800
1995	" "	2,000	0.700	1,400
1998	" "	3,000	0.660	1,980
			TOTAL	$648,246

SALVAGE VALUE = 294,954 X 0.620 = $ -182,871

PRESENT WORTH = $ 465,375

TABLE 19. SUMMARY COMPARISON OF M&R ALTERNATIVES

Alternative	Analysis Period (Years)	Total Present Worth Excl. Sal. Val. ($)	Salvage Value ($)	Total Present Worth ($)	Ratio to Major M&R
1. Major M&R	25	854,111	117,078	737,033	1.00
2. Replace Keel - 1977	25	529,972	185,220	344,752	0.47
3. PCC OL - 1977	25	639,391	218,587	420,804	0.57
4. AC OL - 1977	25	648,246	182,871	465,375	0.63

2. The most economic overall M&R is to replace the central six-slab keel sections with a more adequate structure. This should be accomplished within the next 3 years.

3. Overlaying the entire runway with concrete is a second choice and may be very desirable if the airfield engineer wishes to minimize all future M&R over the next 20 years.

SECTION VIII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

1. The pavement condition survey procedure and the pavement condition index (PCI) developed during FY75 and 76 and described in Volumes I and II were test-implemented at five Air Force bases during FY77. The procedure to calculate the PCI based on results obtained from the pavement condition survey was computerized. Two versions of the computer program were developed: one to operate on the Burroughs 3500, and the other on the CDC 6600 computer. To further assist in the technology transfer of the pavement condition survey and PCI procedures, a distress identification slide presentation was developed for both jointed concrete and asphalt- or tar-surfaced airfield pavements (Section II).

2. Although one of the reasons for visiting the five Air Force bases was implementation of the PCI procedure, the main objective was to collect data for as many pavement features as possible to be used for developing maintenance and repair (M&R) guidelines. A significant amount of information was obtained pertaining to M&R of each feature through interviews with and questionnaires administered to base and major command pavement engineers. In addition, a workshop was held at the US Army Construction Engineering Research Laboratory in which several Air Force major command engineers and others participated in the development of guidelines for determining M&R (Section III).

3. Several important condition indicators were identified for determining the condition of the pavement. The indicators include the mean PCI of the feature, variation of PCI within a feature, the rate of deterioration (or loss of PCI) of the pavement, cause of pavement deterioration (i.e., load, climate/durability, and others), load carrying capacity, skid resistance/hydroplaning, surface roughness, and extent of previous maintenance. Methods for determining and rating each of these indicators are described (Section IV).

4. M&R methods were divided into three general categories: routine, major, and overall. Routine M&R consists of doing nothing (no M&R is required), or preventive and localized M&R. Preventive M&R includes crack and joint sealing, fog seals, and rejuvenators. Localized M&R includes skin patching, small amounts of partial- or full-depth patching. Major localized M&R is an extensive form of localized M&R that includes partial- or full-depth patching, slab replacement, undersealing, surface grinding, reconstruction of joint, and aggregate seal over a considerable area of the pavement. Overall M&R covers the entire pavement feature and usually improves its load carrying capacity. It includes overlays, reprocessing, or recycling, and total reconstruction (Section V).

5. Guidelines were developed for selecting feasible M&R alternatives based on results obtained from the pavement condition evaluation. The mean feature PCI was found to relate strongly to the three M&R categories of routine, major, and overall. M&R zones were established based on the mean feature PCI for selecting the M&R category (routine, major, or overall). Other condition indicators are used to further aid in the selection of feasible M&R alternatives within an M&R zone. Recommended M&R methods for the different distress types and severity levels were developed (Section V).

6. Economic analysis procedures were developed for comparing the different M&R alternatives. The economic analysis assists the pavement engineer in selecting the best of several feasible M&R alternatives for a given pavement feature (Section VI). The use of the evaluation, M&R guidelines, and economic analysis procedures is illustrated by an example application (Section VII).

CONCLUSIONS

1. The pavement condition survey procedure and the PCI can be readily and easily implemented by Air Force base and major command engineers. The engineers, however, must be trained (including field training) to identify pavement distress types, perform inspections, and use the deduct curves to calculate the PCI (Section II). The procedure does not require expensive equipment; only a measuring wheel and straight-edge are needed.

2. A definite correlation exists between pavement condition rating based on the PCI scale and M&R categories (routine, major, overall) (Figure 29, Section V).

a. If the pavement condition rating is excellent or very good, only routine M&R is required. Recommended M&R methods for different distress types and severity levels are presented in Tables 8 and 9. If the condition rating is good or fair, routine, major, or overall, M&R may be needed based on results of pavement condition evaluation as described in Section IV.

b. A condition rating of poor indicates that routine M&R is no longer sufficient to restore the pavement structural integrity and surface operational condition. Use of major or overall M&R will depend on the results of the pavement condition evaluation and economic analysis.

c. A condition rating of very poor or failed indicates that only overall M&R can restore the pavement structural integrity and surface operational condition. Economic analysis is performed to compare the feasible overall M&R alternatives to select the best alternative.

3. The rate of pavement deterioration (based on the decrease of PCI over time) was shown to be a significant factor in pavement evaluation for the selection of M&R alternatives. Accumulation of PCI data over several years will make this information easily obtainable.

4. Sufficient data have not yet been obtained to analyze and make final conclusions regarding the correlation between the PCI and long wave surface roughness. Preliminary analysis, however, indicated that if the long wave roughness was built in during construction (or overlay), there will be little or no correlation. If the long wave roughness has developed over time due to pavement deterioration, there is a strong possibility that a correlation exists.

RECOMMENDATIONS

1. Based upon the successful field trial testing and implementation, it is recommended that the pavement condition survey, rating, and M&R guidelines be implemented by the US Air Force.

2. Work should be initiated to develop procedures to estimate the "consequence" or results of various M&R methods and strategies to aid in the economic analysis. The economic analysis procedures outlined herein provide only approximate results, since prediction of future performance is based on judgment. A preliminary feasibility study was accomplished (Appendix A) which showed that methods of predicting consequences could be developed using statistical theory, field performance data, and analytical pavement analysis methods.

3. It is recommended that work begin immediately on the development of a computerized data base for efficient management of an airfield pavement system. The data base should include, as a minimum, provisions for storage and retrieval of the information obtained from the pavement condition survey and all condition indicators identified in Section IV.

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